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THE LEACHING OF IRON PROTORES: SOLUTION AND PRECIPITATION OF SILICA IN COLD WATER.

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INTRODUCTION.

THIS paper presents the results of an investigation of the solvent action of various cold dilute solutions on silica, and the precipitation of silica from these solutions. Experiments indicate that acid sulphate waters act rapidly on silicates, but do not appreciably affect quartz, jasper, taconite, opal, or chalcedony, unless phosphates or fluorides are present. Alkalies attack all the minerals and rocks tested, though quartz, jasper, taconite, and the silicates suffered much less than opal and chalcedony. The best solvent of quartz, jasper, and taconite was found to be a solution of magnesium bicarbonate. Waters containing bicarbonates of calcium and magnesium attacked all the minerals and rocks that were tried, and to about the same degree.

For the formation of any iron ore from its protore, the silica dissolved must remain in a state of solution. Experiments have previously been reported which indicate that solutions of bicarbonates or of the various electrolytes contained in sea water are common precipitants of silica in nature. The experiments described in this paper seem to show that these reagents generally precipitate silica only from solutions which are much more concentrated than is usual in nature, and that even with concentrated solutions, complete precipitation is extremely rare. Much of the silica which is precipitated as secondary quartz or chalcedony before being finally removed from a protore probably comes out

of solution when acid waters rich in silica are made alkaline in the presence of electrolytes.

SOLUTION OF SILICA IN COLD WATER.

Review of Literature—Silica is unquestionably dissolved in cold descending waters and many of the iron ores of the world have been formed by the leaching of silica by supergene solutions. A number of common salts have been identified in soils;[1]—aragonite, calcite, epsomite, halite, magnesite, soda niter, sodium carbonate, tri-sodium phosphate, and many others. Water percolating through soils containing these minerals would dissolve them in time though usually in the form of a bicarbonate and it is in such solutions that silica must be dissolved in the leaching of iron protores.

From a review of the literature it seems that little experimental work has been done on the solution of silica in cold waters, and the actual form of the silica in solution is still largely a matter of conjecture. It has often been suggested, however, that carbonated waters[2] and alkalies[3] are the principal solvents in nature; sulphate waters may also play an important part.

Experiments[4] have shown that silica can be dissolved in appreciable amounts by cold carbonated waters from the following minerals; hornblende, actinolite, epidote, chlorite, serpentine, "feldspar," adularia, oligoclase, olivene, wollastonite, muscovite, asbestos, talc, quartz, and dioptase.

On the other hand recent work by Cox, Dean and Gottschalk[5] leads them to conclude that "probably the most important electrolyte taking part in the precipitation of colloids in nature is calcium bicarbonate." As silica is probably transported only in

[1] Whitney, Milton, *Science*, vol. LIV., No. 1398, Oct. 14, 1921, p. 350.

[2] Rogers, W. E., and R. E., *Am. Jour. Sci.*, 2d Ser., vol. 5, 1848, p. 401. Muller, Richard, "Tschermak's Min-Mittheilungen," 1877 p. 25–48.

[3] Clark, F. W., "Data of Geochemistry," U. S. Geol. Survey. Bull 694, p. 478.

[4] Matignon, M. C., et Mlle. Mardial, *Compt. Rend.*, vol. 170, May, 1920, pp. 1184–86. Muller, Richard, *loc. cit.*

[5] Cox, Dean, and Gottschalk, "Studies on the Origin of the Missouri Cherts and Zinc Ores," Bull. 2, vol. 3, Mo. School of Mines, p. 6.

the colloidal state in nature[6] this would argue against the efficacy of bicarbonate solutions as solvents of silica.

The experiments of Cox, Dean and Gottschalk apparently contradict those of Matignon and Mlle. Mardial[7] who found that wollastonite was broken down by carbonated water with the formation of calcium bicarbonate and silica, both in solution. This would indicate that calcium bicarbonate acts as a precipitant under some conditions and fails under others.

Alkaline solutions have long been known to be solvents of silica in nature[8] and a logarithmic formula expressing the relation of alkalinity to the amount of silica dissolved has even been proposed.[9]

Little work has been done on the solution of silica in cold acid waters, so far as the writer is aware, yet it may be inferred that sulphate waters are powerful solvents from consideration of the analyses given below. Furthermore, in the treatment of lead-

Locality.	H_2SO_4 Parts Per Million.	SiO_2 Parts Per Million.
Comstock Lode, Nev.[10]	2,575.0	616.0
Burra Burra Mine, Ducktown, Tenn.[11]	406.5	78.9
East Tennessee Mine, Ducktown, Tenn.[11]	129.6	55.6
Capote Mine, Canenea, Mexico.[12]	970.0	76.0

zinc ores a solution made up of fifty parts sulphuric acid, one hundred and nine parts sodium chloride, and nine hundred parts of water is commonly used for leaching, and so much silica is taken into the solution in this process that its presence constitutes a difficult metallurgical problem. The silica precipitates in a gelatinous form when the acid solution is neutralized with lime

[6] Kahlenburg, Louis, and Lincoln, *Jour. Phys. Chem.*, vol. 2, 1898, pp. 79–90.

[7] *Loc. cit.*

[8] Clarke, F. W., *Loc. cit.*, p. 478.

[9] M. Dienert, *Comp. Rend.*, vol. 155, p. 797.

[10] Ried, J. A., "The Structure and Genesis of the Comstock Lode," *Cal. Univ. Dept. Geol. Bull.*, vol. 4, p. 192.

[11] Emmons, W. H., "The Enrichment of Ore Deposits," U. S. Geol. Surv., Bull. 625, p. 87, 88.

or zinc dust, and in this form is hard to filter. A number of different processes have been tried to overcome this difficulty.[12]

Since bicarbonates are thought by some authorities to be precipitants of silica, and by others solvents of it, there seems to be need of more definite information. The effect of acids and alkalies is but vaguely known for the most part, and speculations as to their actual rôle in the leaching of iron protores have but little experimental foundation. The problems thus presented are taken up in the following pages.

CHEMICAL EXPERIMENTS IN THE SOLUTION OF SILICA IN COLD WATER.

A series of experiments lasting more than a year has been made by the writer to determine the effects of certain solutions on various minerals and rocks. The minerals selected are the common protores of iron or their associates; vein quartz, jasper, taconite, greenalite, actinolite, glauconite, opal, and chalcedony. The solvents were suggested by analyses of natural waters.[13] The composition of waters which had appreciable amounts of silica dissolved was noted and the presence of certain radicles in larger amounts than was usual was thought to be of possible significance. The solutions tested were: magnesium sulphate, sodium chloride, sodium hydroxide, sodium carbonate, a mixture of magnesium bicarbonate and magnesium sulphate, a mixture of magnesium bicarbonate and calcium bicarbonate, magnesium bicarbonate, calcium bicarbonate, a mixture of sodium chloride and sulphuric acid, and humic acid. The first four solutions were made up by adding five grams of the substance to a liter of distilled water. The calcium and magnesium bicarbonate solutions were made by running a stream of carbon dioxide through water in contact with the particular carbonate for seventy two hours. The "humic acid" was obtained by immersing a handful of dried peat in five hundred cc. of water and allowing it to remain there throughout the experiments. Two cc. of concentrated sul-

[12] Ralston, Oliver C., "Electrolytic Deposition and Hydrometallurgy of Zinc," pp. 59–60. Betterman, T. O., "Soluble Silica in the Preparation of Zinc Sulphate for Electrolysis," *Min. and Met.*, Dec., 1922, p. 30.

[13] Lane, A. C., U. S. Geol. Surv. Water Supply Paper 31.

phuric and five grams of sodium chloride per liter were used in the acified chloride water.

A gram of each of the minerals to be tested was ground to pass a two-hundred-mesh screen, covered with five hundred cc.

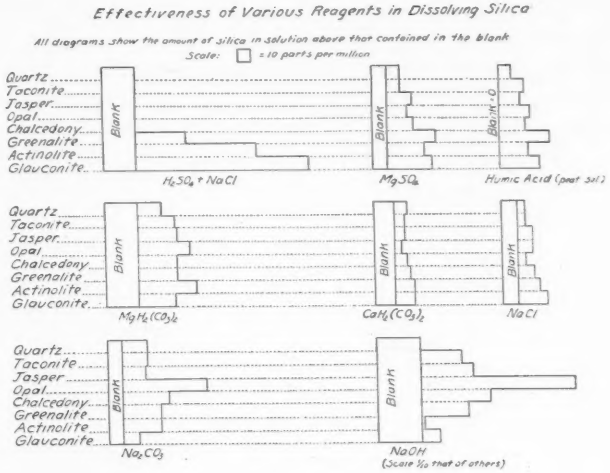

FIG. 71.

of each of the above solutions in a pyrex flask and stoppered with rubber corks. To ascertain the action of the solutions on the containers, a blank for each of the solvents was made up at the same time and analyzed with the corresponding solution of the minerals.[14]

[14] Owing to the large number of analyses which had to be made in the limited time which was available, extreme accuracy was sacrificed for a large number of results which would be approximately correct. The results when tabulated would in themselves indicate any large discrepancies. The method used was as follows: fifty c.c. of solution was acidified with hydrochloric acid and evaporated to dryness and the residue heated to one hundred fifteen degrees Centigrade for fifteen minutes, it was then cooled and digested with concentrated hydrochloric acid. This was diluted with distilled water, filtered, and washed. The precipitate was ignited and weighed as silica. About twenty-five check analyses were made in which platinum crucibles were used and the silica hydrofluorized; these checks indicated a high degree of accuracy for the briefer method in such solutions as were here used.

Sodium Hydroxide.—The existence of sodium hydroxide in nature is questionable. Owing to its activity it is scarcely probable that it would remain as sodium hydroxide long enough to yield tests in streams or other waters. Clark[15] has suggested that when silica was dissolved in the form of an alkaline silicate such as sodium silicate, the silica was hydrolized and colloidal silicic acid and sodium hydroxide were formed. A. S. Cushman found that when powdered orthoclase is shaken up with water an immediate extraction of some of the alkaline salts takes place and colloidal silica or possibly aluminous silicate is formed at the

TABLE I.

SOLUTION OF SiO_2 IN PARTS PER MILLION.

	Blank.	Quartz.	Jasper.	Tacon-ite.	Green-alite.	Opal.	Actino-lite.	Chal-cedony.	Glau-conite.
NaOH:									
23 days.....	180	204	400	160	350	352	372	340	232
267 days.....	340	302	740	676	690	1548	362	876	484
NaCl and H_2SO_4:									
32 days.....	4	28	8	10	4	18	50	4	102
257 days.....	26	26	24	28	72	28	124	24	160
$MgH_2(CO_3)_2$:									
63 days.....	12	32	32	30	30	36	30	36	28
269 days.....	26	44	58	56	58	66	72	58	62
$CaH_2(CO_3)_2$:									
49 days.....	6	16	14	14	20	8	26	12	20
257 days.....	16	8	16	22	26	12	24	26	30
30 days.....	4	12	8	8	8	14	14	8	8
$MgH_2(CO_3)_2$ and $CaH_2(CO_3)_2$:									
30 days.....	8	14	18	26	34	22	20	26	8
90 days.....	.....	.....	.....	32	.....	.....	20	26	12
$MgH_2(CO_3)_2$ and $MgSO_4$:									
30 days.....	3	14	16	16	24	22	4	26	6
	.....	.....	.....	24	32	.....	28	.....	40
$MgSO_4$:									
62 days.....	6	26	20	22	32	22	24	26	38
254 days.....	12	22	32	20	50	28	40	34	48
NaCl:									
36 days.....	0	20	8	12	16	18	12	16	18
257 days.....	12	20	26	20	26	26	28	18	36
"Humic Acid":									
70 days.....	0	10	18	20	40	.....	24	22	32
341 days.....	36	36	30	24	48	24	32	62	80
Na_2CO_3:									
19 days.....	.....	.....	.....	.....	.....	56	.....	.....	.....
233 days.....	12	32	30	32	42	78	42	48	24

[15] *Loc. cit.*, p. 475.

same time. The silica carries with it some of the alkalies (absorbed ions). It seems highly probable that the alkaline reaction obtained by shaking the powdered feldspar with water is due to the formation of sodium hydroxide and potassium hydroxide.

Just how much of the silica dissolved by the sodium hydroxide in Table I. came from the minerals tested and how much should be credited to the walls of the containers is uncertain. The U. S. Bureau of Standards[16] found that pyrex is essentially a borosilicate of aluminum with a trace of arsenic and is more strongly attacked by caustic soda than by any other reagent. The action varied widely on different flasks and beakers, but an average of about .25 per cent. loss of weight occurred on boiling sodium hydroxide in the container for twenty minutes; this would be a loss of about fifty parts per million in the volume used in these experiments.

There is no evidence in Table I. that quartz or actinolite were attacked by the sodium hydroxide, as the amount of silica dissolved from the container would account for all that was found in solution. Glauconite was affected but little, if at all. Taconite, greenalite, and jasper seem to have been dissolved to some extent, while opal and chalcedony were strongly attacked.

Believing that the action of the alkali on the minerals was masked by its attack on the containers, two experiments were conducted with quartz and actinolite in which platinum dishes were used instead of pyrex. A gram each of actinolite and quartz were placed in covered platinum dishes and 100 cc. of NaOH allowed to act on them for two weeks. At the end of this time the solutions were filtered and it was found that .0023 gm. of silica had been dissolved from the quartz and .0028 gm. of silica from the actinolite.

These figures indicate a surprisingly slow rate of attack on these two minerals as compared with opal or chalcedony, but show that all the minerals tested are dissolved to some extent.

[16] Comparative Tests of Chemical Glassware, U. S. Bur. Standards Tech. Paper 107.

Mixture of Sulphuric Acid and Sodium Chloride.—The mixture of sulphuric acid and sodium chloride was a very effective solvent of silicates. The table of results including the blank at the end of eight months shows that quartz, jasper, taconite, opal and chalcedony were unaffected. Although greenalite did not seem to have been attacked at the end of one month, at the end of eight months seventy-two parts of silica per million were in solution. This result was carefully checked by a second analysis. Actinolite was affected to a marked degree by the acid water and glauconite was even more strongly attacked.

In general then, the silicates—greenalite, actinolite and glauconite—were broken down and silica was taken into the solution. while quartz, taconite, jasper, opal and chalcedony seem to have remained practically untouched. It is worthy of note also that iron was found in all but the blank.

Magnesium Bicarbonate.—This was an effective reagent and it is remarkable for the uniformity of its attack on silicates, crystalline quartz and amorphous silica. A variation of only eight parts per million was shown among the eight samples at the end of two months, the average silica taken into solution being thirty-three parts per million. The blank which indicated that twenty-six parts per million were taken into the solution in nine months was much lower than the samples, and the variation among the minerals was greater than at the end of two months, actinolite having been most strongly attacked (seventy-two parts per million) and quartz the least affected (forty-four parts per million). It is probable that even higher results may be indicated, as some of the carbon dioxide in the waters unquestionably escaped during the hot summer months with a consequent loss of strength of the solutions and partial precipitation of silica.

Calcium Bicarbonate.—Calcium bicarbonate is not nearly as strong a solvent as the magnesium bicarbonate but its action is similar, and all the analyses indicate a slight solvent action on the various minerals. The three silicates show the highest figures for dissolved silica, the crystalline and cryptocrystalline varieties being acted on to a lesser extent. As with magnesium bicar-

bonate solution, some carbon dioxide escaped during the summer, so that the figures for eight months may be too low.

A scale-like precipitate formed on the walls of some of the containers in which solutions of bicarbonates were present. This precipitate formed very slowly—over a period of months—and was invariably present in the flasks which contained quartz, jasper, taconite, opal, and chalcedony, while the blank and the flasks containing the silicates contained no trace of it. It seems reasonable to suppose that the scale was formed because of the loss of carbon dioxide; and since the scale contains twenty-eight to twenty-nine per cent. FeO and thirty-nine to forty-one per cent. SiO_2, it is probable that the silica was deposited from solution.[17] Hence it may be inferred that the figures do not give the maximum amount of silica which was taken up by these reagents.

Sodium Carbonate.—Sodium carbonate seems to be a fairly effective solvent attacking all of the samples to some extent. Opal yields by far the largest amount of silica (seventy-eight parts per million), while the other minerals ranged from forty-eight parts per million for chalcedony to twenty-four parts for glauconite. The blank to be subtracted is small.

Magnesium Sulphate.—All the solutions of magnesium sulphate dissolved silica in excess of that found in the blank. The amount taken up from the most of the samples at the end of two months is practically the same as that found in the solution six months later; this would indicate that equilibrium had been established. The three silicates show the greatest solubility.

Magnesium Bicarbonate and Calcium Bicarbonate.—The effectiveness of a solution containing both of these bicarbonates seems to be about the same as that of a solution of magnesium bicarbonate alone; if anything the action is less.

[17] This precipitate formed in all solutions where bicarbonates were present in the flasks containing quartz, jasper, taconite, opal, and chalcedony. It was insoluble in cold dilute acids but easily dissolved in warm acids; it was colorless to light yellow, anisotropic and had an index of refraction of 1.74. The presence of the precipitate in all the flasks excepting those containing the silicate minerals or the blank, suggests that the silica dissolved from silicates is in a different form in the solution from that dissolved from the other minerals.

Magnesium Bicarbonate and Magnesium Sulphate.—The analyses of the samples containing both magnesium bicarbonate and magnesium sulphate indicate that no increased solvent action results from using such a mixture. The attack is slightly greater than that of magnesium sulphate alone and slightly less than that of magnesium bicarbonate by itself. This latter fact may be caused by the repression of ionization of the magnesium bicarbonate due to the presence of magnesium sulphate in the same solution.

Sodium Chloride.—The solution of sodium chloride had little effect on the various forms of silica; though the silicates showed a slightly greater tendency to solution than most of the other minerals. Pure water may be as effective.[18]

Humic Acid.—Glauconite, chalcedony and greenalite are undoubtly attacked by solutions derived from peat. The high amount of silica in the blank at the end of eight months is difficult to account for, but as the result was checked by four separate analyses it is probably correct. Some small amount of silica may have been present in the peat and when this was exposed to the action of the humic acids the amount of silica dissolved rose till it corresponded to that of the other samples. We may safely conclude that humic acids have some solvent effect on silica.

Fluorite, Apatite, and Phosphate, in Sulphuric Acid Solution and in Carbonated Water.—To test the possibility that phosphoric or hydrofluoric acids—which are the only acids that attack quartz glass[19]—were formed in the decomposition of fluorapatite and helped in the solution of silica, certain experiments described below were performed. The figures indicate the parts per million of silica in solution at the end of one month.

These figures on comparison with Table I. indicate that the presence of phosphates and fluorides would materially aid the solution of silica in acid solutions—both from silicates and the more stable quartz and taconite.

[18] Rogers, W. E., and R. E., *Loc. cit.*, p. 3.

[19] Gilard, P., "Le Verre de Quartz," *Rev. Univ. Mines*, Jan. 1, 1922, p. 76.

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TABLE II.

Mineral.	Solutions.			
	1 cc. H_2SO_4 .5 gm. Fluor.-Apatite. 500 cc. H_2O.	1 cc. H_2SO_4 .5 gm. Fluorite. 500 cc. H_2O.	1 cc. H_2SO_4 .5 gm. Phosp. Rock. 500 cc. H_2O.	Slow Stream of CO_2 .5 gm. Apatite. 500 cc. H_2O.
Blank.....	4	.....	.....	.....
Quartz.....	36	.....	.....	16
Taconite.....	40	30	40	16
Greenalite....	102	.....	.....	.....

RECAPITULATION.

1. Acids, carbonated water and alkalies dissolved silica in cold solutions.

2. The acids attack silicates strongly, leaving unaffected the minerals consisting of silica uncombined chemically, unless phosphates or fluorides are present.

3. Alkalies dissolve opal readily, but as this is a relatively rare mineral this reaction is unimportant in iron ore formation; chalcedony is most strongly attacked of the remaining minerals tested, though all were affected to some extent.

4. Solutions of bicarbonates attack all the minerals tested, and are the most active solvents of quartz, jasper, and taconite.

5. The behavior of certain minerals is similar with different solutions and a general grouping may be made as follows:

(*a*) Silicates, most effectively acted on by acid solutions.

(*b*) Opal and chalcedony, most effectively acted on by alkalies.

(*c*) Quartz, jasper, and taconite, most effectively acted on by solutions of bicarbonates.

PRECIPITATION OF SILICA.

The leaching of protores of iron depends on the solution of silica and its transportation in that state. Both iron and silica are readily dissolved in acid solutions but the iron, however, is concentrated while the silica disappears during the formation of many iron ores. Hence some study of the conditions favorable

or unfavorable to its precipitation is necessary to discuss intelligently the formation of an iron ore from its protore.

So far as is known, silica is transported only in the colloidal state in natural solutions [20] and therefore practically all accounts of the solution and precipitation of silica involve colloidal chemistry [21] but in as brief a paper as this, a discussion of colloidal chemistry as applied to geology must be omitted.

In view of the discordant results obtained by different investigators,[22] the results of the experiments in the precipitation of silica and the conclusions derived from them are put forward with hesitation, and the writer feels that as more work is done in this field some of his conclusions may have to be modified.

Experiments in Precipitation.—It has been suggested by Tarr [23] that the silica carried in streams is precipitated on reaching the ocean by the electrolytes such as magnesium sulphate, sodium chloride, potassium sulphate, contained in the sea. A dilute solution of water glass containing from thirteen to twenty-seven parts of silica per million (about the proportion found in streams) was precipitated by the addition of electrolytes. Using artifical sea water a heavy precipitate was obtained at once. Using sodium chloride alone a slight precipitate was formed which became heavy on the addition of magnesium sulphate solution. These experiments are used as evidence that silica carried by rivers is precipitated on reaching the ocean. The amount of silica left in the filtrates after the precipitation by electrolytes is not stated. The writer duplicated Tarr's experiment but did not obtain similar results and the experiments tabulated below were undertaken to obtain a clearer understanding of the action

[20] Kahlenberg, Louis, and Lincoln, *Jour. Phys. Chem.*, vol. 2, 1898, pp. 79–90.

[21] Hubbard, G. D., "Colloids in Geologic Problems," *Am. Jour. Sci.*, vol. IV., fifth series, Aug., 1922, pp. 96–110. Taylor, W. W., "The Chemistry of Colloids." See also the following: "Chemistry of Colloids," Zsigmondy-Spear; "Chemistry of Colloids," Ostwold-Fischer; "A System of Physical Chemistry," vol. I., Lewis; "Applied Colloidal Chemistry," Bancroft.

[22] Taylor, W. W., *Loc. cit.*, pp. 125–127.

[23] Tarr, "Origin of Chert in the Boone Limestone," *Am. Journal of Science*, 1917, p. 413.

of electrolytes in the precipitation of SiO_2. In these experiments filtered natural sea water was used as the precipitant.

TABLE III.

Solution Tested.	Exp.	Amount of Sea Water Used as Precipitant.	Gms. SiO_2 in Precipitate.	Gms. SiO_2 in the Filtrate.	Parts per Million of SiO_2.	
					Filtrate.	Recalculated, see Text.
50 cc. of very dilute Na_2SiO_3 solution.....	A	10 cc.	0.0000	0.0018	30	36
(.0035% SiO_2).....	B	50 cc.	0.0000	0.0017	17	34
50 cc. of dilute Na_2SiO_3 solution.....	C	10 cc.	0.0104	0.0144	240	282
(.0490% SiO_2).....	D	50 cc.	0.0106	0.0138	138	275
50 cc. moderately strong Na_2SiO_3 solution.....	E	10 cc.	0.1554	0.0404	673	673
(.30% to .40% SiO_2)...	F	50 cc.	0.1390	0.0150	150	255

In those experiments where a precipitate was obtained, the amount of silica in the filtrate is nearly constant except in experiment E. This exception supplies a key to the behavior of the silica in all the experiments. Here it is believed that 10 c.c. of sea water contained only sufficient electrolytes to precipitate 0.1554 gram of silica. In other words 1 c.c. of sea water could precipitate 0.0155 gram of silica. It appears that complete precipitation does not occur and when the silica content of the sodium silicate solution is decreased to a certain amount any further addition of electrolytes serves only to dilute the solution.

Thus with the "very dilute" solution of sodium silicate no precipitate formed. In the "dilute" solution, less than 1 c.c. of sea water precipitated all the silica that came out of the solution and the remaining quantity added merely diluted the filtrate. Similarly with the "strong" sodium silicate solution, about 9 c.c. of sea water were used to precipitate the silica obtained in experiment F and the 41 c.c. of further addition only diluted the filtrate

A calculation of the amount of silicate left in the filtrate at the time precipitation ceased, gives the figures in the last column. These indicate that about 275 parts of silica per million may be

dissolved in a slightly alkaline solution in the presence of rather large amounts of electrolytes.

It is worth noting that the true gel—in which the liquid seems to become more and more viscous and finally to solidify—was only obtained by neutralizing acid or alkaline solutions of silica or carrying them slightly past the neutral point. Such true gels were not obtained at all in solutions containig less than 0.10 per cent. silica and only on standing for many hours if the solution contained less than 0.75 per cent. silica. Neutral salts such as magnesium sulphate, sodium chloride, barium chloride, always gave the flocculent white precipitate instead of the true gel even with solutions containing 4.00 per cent. silica (40,000 parts per million).

It is thought that this may be due to the fact that the silica absorbs H and OH ions in neutral solutions at or near its isoelectric point with the consequent formation of H_2SiO_3 nH_2O or a true gel. When precipitated by sodium chloride or some other neutral salt the ion of opposite charge is absorbed, neutralizing the charges already carried; repulsion of the particles of the sol ceases and coagulation takes place. This precipitate always carries down a small amount of the precipitating ion and some water, though needless to say, it is much less hydrated than the true gel.

Some published analyses give further evidence that saline waters may contain large amounts of silica.[24] Thus in the large Soda Lake, Lahontan basin, Nevada, out of a total salinity of 11.37 per cent. there is from .24 per cent. to .25 per cent. of silica. This would indicate that 284.25 parts of silica per million are dissolved in lake waters which are more than three times as concentrated as sea water. This figure is surprisingly close to the amount of silica in the filtrates in experiments *C, D,* and *F* above. This lake differs from many other lakes of closed basins, and from the ocean, in that it is slightly alkaline,—and this may have something to do with the small silica content of the ocean and of most interior basin lakes. The ocean contains less than five parts of silica per million.[25] These facts indicate that the factors

[24] Clark, F. W., "Data of Geochemistry," U. S. Geol. Surv. Bull. 695, p. 157.
[25] Clark, *op. cit.*, p. 119.

governing the precipitation of silica are not clearly understood and that more research is needed along this line.

In some recent work by Cox, Dean, and Gottschalk, experimental evidence is given which leads them to the conclusion that "probably the most important electrolyte taking part in the precipitation of colloids in nature is calcium bicarbonate."[26] In their experiments dialized silica[27] was placed in tubes with powdered calcite. No precipitate formed until carbon dioxide was introduced, when a precipitate came down. In a sealed tube of dialized silica and powdered calcite no precipitate formed in a year, while in the bottle containing dialized silica alone, at the end of three months most of it had precipitated. Hence calcium carbonate alone was thought to be a peptiser—a substance which inhibits the precipitation of colloids—and calcium bicarbonate a precipitant of colloidal silica.

In carrying out similar experiments the writer used dilute solutions of water glass acidified with hydrochloric acid and dialized until free from chloride as shown by a silver nitrate test.

TABLE IV.

Exp.	Substance.	Reagent.	Results.	
			Precip.	Filt.
No. 1	10 cc. dialized SiO_2	20 cc. $CaH_2(CO_3)_2$	.0000 gm.	.....
No. 2	Filt. from No. 1	CO_2 and .5 gm. $CaCO_3$	.0002 gm.	.0096 gm.
No. 3	10 cc. dialized SiO_2 boiled to 5 cc	20 cc. $CaH_2(CO_3)_2$	.0005 gm.	.....
No. 4	Filt. from No. 3	CO_2 and $CaCO_3$	.0000 gm.	.0065 gm.
No. 5	10 cc. strong dialized SiO_2	10 cc. $MgH_2(CO_3)_2$	.0202 gm.	.0017 gm.
No. 6	30 cc. of fresh strong dialized SiO_2	CO_2 for 20 minutes	.0060 gm.	.....

Experiments 1, 2, 3, and 4 show that dilute dialized silica solutions can retain considerable silica in solution in the presence of calcium bicarbonate. However, calcium bicarbonate un-

[26] *Loc. cit.*, p. 6.

[27] Colloidal silica freed from electrolytes by contact with a semi-permeable membrane (such as collodion) through which a true solution may diffuse but which will not allow a colloid to pass.

doubtedly is a precipitant of colloidal silica in solutions containing four per cent. or more of silica. Using fresh dialized silica of about this strength a heavy precipitate formed immediately on adding calcium bicarbonate; on diluting the fresh dialized solution one to one and adding the calcium bicarbonate no precipitate formed in twenty-four hours. Other experiments with strong solutions of dialized silica showed magnesium bicarbonate to be a more effective precipitant than calcium bicarbonate. In experiment No. 2, about 280 parts per million of silica were in the filtrate: in experiment No. 4, there were about 185 parts per million; in experiment No. 5, about 85 parts per million. In natural waters there is seldom more than 35 parts per million, so that it is probable that calcium bicarbonate and magnesium bicarbonate rarely act as precipitants of silica in nature.

In order to approximate natural conditions of precipitation, some of the solutions used in the experiments on the solubility of silica (Table I.) were mixed. These solutions contained only the silica which they had dissolved from the minerals in the pyrex flasks in the course of a year. The results are given below.

TABLE V.

Solutions Mixed		Results	
H_2SO_4—NaCl sol.	Sol. added	Precip.	Filt.
1. 9 cc. (sol. from actinolite).....	31 cc. Mg. bicarb. (sol. from actinolite)....	SiO_2 .0004 gm. Fe_2O_3 .0014 gm.	....
2. 16 cc. (sol. from greenalite).....	55 cc. Mg. bicarb. (sol. from greenalite)....	SiO_2 .0003 gm. Fe_2O_3 .0027 gm.	.0029 gm. .0000 gm.
3. 50 cc. (sol. from glauconite).....	100 cc. Mg. bicarb. and Ca. bicarb. (sol. from glauconite).....	SiO_2 .0002 gm. Fe_2O_3 .0130 gm.	.0110 gm. .0000 gm.
4. 50 cc. (sol. from glauconite).....	10 cc. Fresh dilute Na_2CO_3.....	SiO_2 .0020 gm. Fe_2O_3 .0126 gm.	.0068 gm. .0000 gm.
5. 100 cc. from actinolite.....	35 cc. Na_2CO_3.....	SiO_2 .0071 gm. Fe_2O_3 .0069 gm.	.0074 gm. .0002 gm.

In each experiment the final solution was alkaline to litmus.

The writer believes that these experiments indicate that complete precipitation of silica is difficult and probably quite rare in nature.

The factors governing the precipitation of silica where it does occur, while not clearly understood, are probably related to the change in the solutions from acid to alkaline, or to the mixing of two solutions, one rich in electrolytes and the other containing a relatively large amount of silica. The basic reason for the precipitation is believed to be the neutralization of the electric charge carried by the silica sol.

GEOLOGIC APPLICATIONS.

Although both iron and silica may be dissolved in acid solutions above the water table, the character of the solutions changes, on sinking to or near this level, from acid to alkaline, and practically all of the iron is precipitated. In the dilute natural solutions it is thought that but little silica is precipitated with the iron, and that by far the larger part remains in solution and is carried off by ground water.

When leaching of a protore of iron begins, it is probable that the percolating waters are more acid than later in the leaching process, since the acid forming sulphur compounds break down more readily than most of the other minerals present. In these acid waters the silicates would be readily dissolved and if sufficient sulphides were present in the formation, all of the silicates would be completely broken down. More commonly the action started by the acid waters would be carried to completion by solutions of bicarbonates, particularly magnesium bicarbonate. Quartz, jasper, and kindred forms of silica would then be subject to attack, while the iron would be much less affected. Thus the solution of the silicates would be the initial step and the slower attack on the quartz and jasper would follow. The increased porosity due to the solution of the silicates is thought to be an important factor in aiding the complete leaching of silica from the rock.

For the sake of clarity in presenting the subject, the processes above referred to are spoken of as if one followed the other. The solution of the silicates would not, of course, be carried to completion before quartz or jasper are attacked. Yet such

minerals as greenalite, actinolite, and other silicates would be the first to be broken down.

It is probable that as erosion reaches down to a rock, solution of silica starts below ground water level in the alkaline zone, but in a formation containing a large percentage of silicates (as the greenalite of the Mesabi) the amount of leaching that would occur is not thought to be important.

The foregoing discussion is intended to outline the dominant processes in the leaching of silica from iron protores. Local variations occur; silica may sometimes be dissolved and precipitated and redissolved many times before it is finally removed, but acid waters and solutions of the alkaline earth bicarbonates seem to be the reagents best adapted to the leaching of silica from protores of iron.

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ORIGIN OF THE PLACER GOLD OF THE BARKERVILLE AREA, CARIBOO DISTRICT, BRITISH COLUMBIA, CANADA.[1]

W. L. UGLOW AND W. A. JOHNSTON.

INTRODUCTION.

THE placer mines of the Barkerville area have produced, since 1860, at least 30 millions of dollars in gold and although the great part of the yield was obtained in the 60's and 70's, varying amounts of gold have been produced annually since that time. This area embraces some 210 square miles and is part of the Cariboo district of Central British Columbia. The town of Barkerville is the center of the area and is about 60 miles east of the town of Quesnel on Fraser river in latitude 53 north. The main producing creeks of the Cariboo district, Williams, Lightning and Antler and their tributaries, lie in the Barkerville area.

The area was geologically examined and mapped by the authors in 1922 for the Geological Survey of Canada, and a Memoir on the geology is now in the course of preparation. The present paper is the outcome of one of the problems suggested by the field work. The origin of the placer gold of the area has been discussed by A. J. R. Atkin[2] and has been referred to incidentally by several other writers who have examined parts of the district.

The present writers wish to express their indebtedness to Messrs. John Hopp, F. J. Tregillus and A. W. Sanders for the loan and gift of nuggets and crystals of gold and to many other mining men in the district for coöperation and assistance in the work. Acknowledgments are also due to Dr. V. Dolmage of the Geological Survey, Canada, for the preparation of photomicrographs of gold nuggets, and to Dr. H. C. Cooke of the Geological Survey for critical reading of the paper.

[1] Published with the permission of the Director, Geological Survey, Canada.

[2] "The Genesis of the gold-deposits of Barkerville (British Columbia) and the Vicinity," *Journal of the London Geological Society*, vol. 60, 1904, pp. 389–393.

STATEMENT OF THE PROBLEM.

The question of the source of the placer gold in the Cariboo district, British Columbia, has been one of interest to mining men and prospectors almost since the discovery of the placers. The fabulous richness of the placers in certain restricted parts of several of the creeks—2½ miles of Williams creek and its tributaries, for example, being credited with a production of about 19 millions of dollars[3]—and the coarseness and angularity of much of the gold were strong indications that the placer gold was of decidedly local origin. After the exhaustion of the richer portions of the gravels in the 70's, the attention of prospectors was directed towards a search for the mother lode. The only occurrence of auriferous lodes in the region is a belt of quartz veins which crosses the drainage basins of the creeks; and deposits located in this belt were prospected by means of tunnels and shallow shafts. Free gold was found only in the upper, disintegrated and decomposed parts of the veins, but not in quantities that seemed large enough nor of the proper character, to be the source of supply of the gold for the rich placers.

The problem of the origin of the placer gold, therefore, should be solved by the answers to the following questions:

(1) Was the placer gold derived from these auriferous quartz veins?

(2) Are the quartz veins, as at present exposed, merely the roots of deposits whose upper eroded portions contained much greater quantities of primary free gold?

(3) If not, and assuming that the upper eroded parts of the veins contained minerals similar to those of the parts now exposed, is there any evidence to show that the placer gold might have been derived from the veins?

(4) If the evidence points in the direction just indicated, what combination of processes could explain the derivation of the placer gold from the veins?

(5) Does the geological and physiographical history of the region show that conditions were favorable for such a derivation?

[3] Ann. Rept. Minister of Mines, B. C., 1896.

SUMMARY OF CONCLUSIONS.

(1) The placer gold of the region is undoubtedly derived from the belt of auriferous quartz veins.

(2) The auriferous constituents of the unoxidized parts of the veins are the sulphides, arsenopyrite and pyrite. There is no evidence indicating that the eroded parts of the veins were richer in primary free gold than the remaining parts. It is probable that they contained minerals similar to those of the lower parts.

(3) Deep decomposition of the veins during Tertiary time resulted in the oxidation of the sulphides and the removal of the soluble constituents. Part of the fine gold thus set free from the sulphides formed enrichments in the oxidized parts of the quartz veins. Gold enrichment also took place by means of the solution of the gold thus released followed by its deposition in the form of crystals, crystal groups, plates, or veinlets and irregular masses, in cracks and cavities in the veins and adjacent country rock near the base of the zone of oxidation. The crystal groups, plates and irregular masses thus formed and subsequently modified by the action of the streams are the main source of the nuggets in the gravels.

(4) The agencies by which solution and deposition of the gold were effected are not definitely known, but it is probable that the solvents were chiefly chloride solutions containing manganese. Precipitating agencies are abundant in the veins and country rock in the form of siderite, pyrite and carbonaceous material.

(5) During early and middle Tertiary time the area was being reduced to a peneplain—probably under semi-arid conditions—and, therefore, conditions were suitable for deep secular decay, for slow removal of the products of decomposition, and for gold enrichment in the oxidized parts of the quartz veins. In late Tertiary time, uplift of the region caused rejuvenation of the streams. Deep valleys which, for the most part, coincided with the ancient valleys were cut and in them the gold, liberated in the zone of Tertiary weathering and concentrated in the old stream valleys, was reconcentrated.

(6) In Pleistocene time nearly stagnant ice-sheets covered the

region but accomplished little erosion; valley glaciers were not sufficiently extensive or long-lived to be effective agents of erosion; while the valley bottoms were protected from erosion because of the narrowness of the valleys and the presence of outwash deposits overlying the Tertiary gravels. A part of the Tertiary gravels, therefore, was preserved. Some of the placers are post-glacial in age and are the result of the concentration by streams of the gold in the gravels, which were caught up, by means of ice-erosion, in the glacial drift. The Tertiary belt of weathered rocks was largely removed by ice-erosion. In places, however, deeply weathered rocks occur beneath unweathered glacial drift showing that the products of Tertiary weathering were not entirely removed by the ice. Since the depth of post-glacial weathering is slight, it is probable that the upper oxidized and highly fractured parts of the veins containing free gold are, in large part, remnants of the Tertiary belt of weathered rocks.

TOPOGRAPHY AND GENERAL GEOLOGY.

The district in which the placers occur is part of an uplifted and highly dissected plain-like surface, which now has elevations varying from 5,500 to 6,300 feet above sea level. The streams flow, for the most part, in comparatively narrow and deep V-shaped valleys incised into the upland. In places, near the headwaters of the streams, the valleys have the U-shaped cross-section characteristic of glacially-eroded valleys. They broaden out in their lower parts, where they are deeply drift-filled and have alluvial flats. The main producing creeks head in Bald mountain plateau near the central and highest part of the area, flow north, northeast and northwest, and, at a few miles from their sources, occupy valleys, the bottoms of which are about 2,000 feet below the plateau level. The depth of the present valleys and the geological structure show that several thousand feet of rock have been eroded from the region.

Two series of metamorphosed sedimentary rocks occur in the area. The lower or Cariboo series, which consists of quartzite, sericite schist, slate and limestone, underlies unconformably

the Slide Mountain series[4] of Mississippian age, which is made up of conglomerate, crinoidal limestone and thinly-bedded chert and argillite. There are two sets of minor intrusives: felsite and quartz porphyry dikes and sills are found cutting the Cariboo series while diabase and diorite dikes and sills cut both formations, but are mainly evident as concordant injections in lit-par-lit relations with the chert and argillite beds. All of these formations are folded into an anticlinorium whose axial direction is northwest. Two series of auriferous quartz veins, described elsewhere, occur in the Cariboo series.

The placer deposits are partly post-glacial and partly pre-glacial. A part also may be Pleistocene and due to concentration by glacial streams. The pre-glacial deposits are by far the most important. While no fossil evidence regarding their age is available, it is evident that they are pre-glacial and Tertiary from the fact that they lie on bedrock beneath the glacial drift and because only by the wearing away of a considerable thickness of the bedrock and concentration of the gold by streams could the rich placers have been formed. As comparatively little stream erosion of the bedrock has taken place in Quaternary time, the rich goldbearing gravels lying on bedrock must be Tertiary in age. The gold content of the post-glacial and glacial gravels was derived partly by stream erosion of the glacial drift—which contains small amounts of gold included in it—and partly from erosion of the pre-glacial gravels and bedrock, into which the present streams have cut in a few places. The area is largely drift-covered—especially the valley bottoms, which in places are filled to a depth of 300 feet—and erosion, since the disappearance of the glaciers, has been limited. The post-glacial gravels are, therefore, of little importance except locally.

Glaciation of the area, in Pleistocene time, was effected by a large confluent ice-sheet or ice-sheets and to some extent also by valley glaciers. The presence of erratics on some of the highest

[4] Previously called "Bear River Series," but here changed to "Slide Mountain Series" to avoid confusion with McConnell's "Bear River Series" of Portland Canal district, B. C.

summits and the existence of glacial striæ at high levels show that an ice-sheet covered the whole area and that the general direction of ice-movement was towards the southwest. That this movement, however, was slight is shown by the fact that the greater part of the drift in the several valleys is local in origin. At the close of the Ice Age, small glaciers occupied several of the valleys and accomplished some erosion of the bedrock. This erosion probably accounts for the absence of placer gold in the upper parts of some of the valleys. Glacial drift, consisting of boulder clay, and stratified silt, sand, and gravel is abundant in the area, except at the higher levels, and shows that in places at least there was considerable ice-erosion of the bedrock. The presence of pre-glacial gravels in the valley bottoms, however, shows that the pre-glacial topography was not greatly modified by ice-erosion. Outwash gravels formed in advance of the ice and the narrowness of the valleys protected the valley bottom in many places from erosion.

DERIVATION OF PLACER GOLD FROM AURIFEROUS QUARTZ VEINS.

The placer gold occurs along with other heavy residuals such as pyrite, galena, scheelite and barite most abundantly in poorly assorted angular and partly rounded gravel mixed with yellow or

FIG. 72. Crystals of placer gold, from Stouts gulch and Lowhee Creek, Barkerville, B. C.; natural size. Loaned by John Hopp.

blue clay derived from disintegration of the gravel, and in broken and partly disintegrated bedrock (in part ancient talus or "slide-rock") and in cracks and crevices in the bedrock in the bottoms

of the Tertiary channels. A large part of the gold is in the form of only slightly worn crystals, crystal groups (Fig. 72), plates and irregular masses, which certainly have not been transported very far. The association of quartz, galena and pyrite with gold in the nuggets also proves that the amount of transportation has been slight.

Small crystals and crystal groups of gold, similar to those found in the stream gravels, occur in the upper oxidized parts of quartz veins within the drainage basins of the creeks. Crystals with hopper-shaped faces are found frequently under both conditions of occurrence. Pebbles of foliated galena and scheelite occur abundantly in the gravels; they are found also in the auriferous veins.

The greater part of the gold from each creek is known to possess fairly definite characteristics. This feature is so marked that the old merchants who handled a great deal of the gold could tell by inspection the creek or creeks from which various specimens were obtained. A small part of the gold—apparently derived from the drift—is usually of a different character and some creeks have different kinds of gold in different parts. The fact, however, that much of the gold from each creek has fairly definite characteristics shows that it is derived locally. Many of the nuggets, also, are too large to be transported any great distance by streams and it is probable that they have moved vertically downward, nearly as far as they have been transported horizontally.

There is a close areal relationship between the upper limits of the rich placers of the various creeks and the location of the northwesterly trending belt of auriferous quartz veins. This was emphatically indicated in 1888 by Amos Bowman,[5] who outlined on his map of the Cariboo district the boundaries of the rich placers and showed their relationship to the quartz veins.

There can be little doubt, therefore, that the gold of the placers was derived from the auriferous quartz veins, the main problem

[5] Report on the Geology of the Mining District of Cariboo, B. C., Ann. Rept., Geol. Surv. Can., 1887, part *C*.

being to determine how the placer gold could have been formed from quartz veins of such character as those found in the Barkerville area.

CHARACTER OF THE PLACER GOLD.

Very little flour gold or even fine scale gold occurs in the area, apparently because of the high gradient of the streams. In several of the valleys the gold is progressively finer downstream and is coarsest in the upper parts, where, however, there is no assortment into sizes, and heterogeneity of both size and shape is the rule. Flattened grains and pellets up to $\frac{1}{20}$ inch in diameter are abundant. Nuggets of various weights up to about 37 ounces have been found and are commonly well-worn, but many are only slightly worn and contain imbedded in them grains of quartz or pyrite.

Many specimens show crystal forms (Fig. 72). These are usually the dodecahedron and groups of dodecahedrons. Cubes and octahedrons are also observed. Some of the angular material shows a columnar structure, the result of incipient crystallization. Most of the crystal specimens show some rounding, indicating wear rather than growth in the gravels. The slight amount of wear is readily explained by the fact that the crystals occur in crevices in the bedrock and in slide rock (ancient talus) in the bed of the streams and, therefore, were protected from abrasion by the streams. They may have been included in cavernous or fractured quartz when introduced into the gravels and were thus protected.

Some specimens consist of gold with small amounts of quartz, while others show a fragment of quartz with a small amount of gold in veinlike form through it. Others show many intermediate phases between these two end cases. Specimens, also, have been found consisting of brecciated quartz, of which the various fragments are held together by a veinlike cement of gold.

Thick plate-like pieces of gold with the edges and corners rounded, weighing up to three ounces, have been found. The sides of the plates show linear ridges of gold separated from one another by polyhedral depressions. The plates resemble fissure-

fillings and the linear ridges represent veinlets of gold deposited in subsidiary cracks in the walls of fissures.

In many specimens the rugged protuberances on the more angular pieces of placer gold may be seen slightly rounded and bent over, just as one would expect them to be shaped in the transition from vein gold to placer gold. Many of the curved protuberances enclose, in the concavity beneath them, angular fragments of quartz, which had not been separated from the gold by abrasion. When the bending of these salient parts of the angular gold has proceeded to a more advanced stage, the quartz grains become entirely embedded in the nugget. The mammillary character of the surface of many of the nuggets is probably explained by such a process.

One slightly worn piece of angular gold shows on both sides a number of triangular depressions shaped like the corner of a cube, from which crystals of pyrite have no doubt been removed.

Many specimens of galena, found in the placer deposits, show small amounts of free gold. Close inspection of several such specimens and of polished surfaces of them revealed the fact that the gold occurs in veinlets or in well-developed cleavage cracks in the galena or in reëntrant portions of the specimens. One specimen, consisting of brownish sericite schist from the country rock of the region, showed veinlets of gold traversing the rock, both parallel and transverse to the schistosity.

Polished and etched nuggets (Figs. 73 and 74) from the district show several features, which throw some light on the origin of the placer gold. Nugget No. 1 (Fig 73) shows crystal faces but is somewhat worn; the other nuggets are well worn. The nuggets when polished and etched show a definite crystalline structure and it is probable, as has been found in other regions,[6] that nearly all the placer gold as well as the vein gold is crystalline, and only a small part concretionary. Nugget No. 1 is composite and consists of a large crystal occupying the middle part with additional crystal growths at both ends. All the nuggets show

[6] Liversidge, A., *Jour. Roy. Soc. N. S. W.*, XXVIII., 1893, p. 343; *ibid.*, XXXI., 1897, p. 79; *ibid.*, XL., 1906, p. 161.

cavities and inclusions. Two of the nuggets (Nos. 3 and 4) apparently contain gold of different fineness, one part being higher in silver than the other part. This is shown by the fact that when

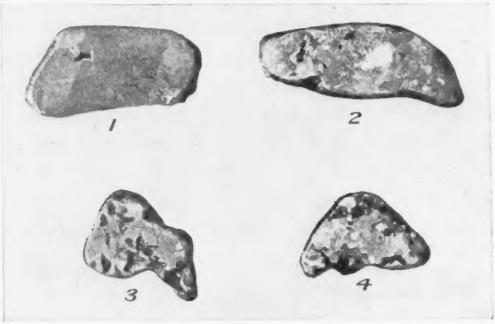

FIG. 73. Polished and etched gold nuggets from Cariboo, B. C.; magnified two diameters.

the surface is etched with aqua regia one part turns a persistent gray whereas other parts remain bright. The contact between the two kinds of gold is an irregular but sharply defined line (see Fig. 74). The bright gold is not due to leaching of the silver

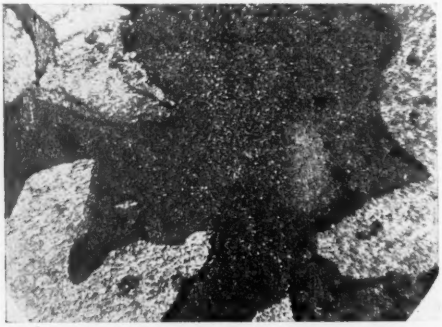

FIG. 74. Polished and etched surface of a gold nugget from Cariboo, B. C., showing the irregular contact of gold crystals of different fineness; magnified 128 diameters.

content of part of the gold in the nugget, for, in places, particles of bright gold are completely enclosed in the grayish gold. A narrow band of bright gold around the outside of the nuggets, however, is probably due to leaching of the silver content. Assays of two pieces cut from nugget No. 4, Fig. 73, were made by the Mines Branch, Department of Mines, Canada. The nugget was first treated with aqua regia to remove its outside portion. Two pieces weighing about one tenth gramme were then cut from the nugget in such a way that one piece contained a greater quantity of the bright colored gold than the other piece, but, because of the intimate relationship of the two kinds of gold (see Fig. 74), no definite separation could be made. The polished surface of the nugget, when slightly etched, showed distinct patches of bright and dark colored gold; when thoroughly etched the whole surface turned dark, owing to the formation of a surface film of silver chloride, the nugget being high in silver. The results of the assays showed that one piece of the nugget contained 80.04 per cent. of gold and 18.33 per cent. of silver and the other 81.37 per cent. of gold and 17.38 per cent. of silver. While the evidence is not as definite as might be wished, it seems probable that some of the nuggets were formed by deposition from different kinds of gold solutions and, therefore, by a process of gradual accretion.

The cavities and inclusions in the nuggets are probably partly due, as pointed out above, to modification of the shapes of the nuggets by the action of the streams. Some of the cavities are probably due to removal by solution of pyrite in the gold, this action having taken place, largely, during the time of formation of the nugget.

The placer gold varies in fineness from about 775 to about 950. The vein gold is said to vary in fineness from 850 to 910.[7] The marked difference in fineness of the gold of different creeks is probably mainly due to differences in the character of the vein gold, from which the placer gold was derived, and only slightly to

[7] Atkin, A. J. R., "Some Further Considerations of the Genesis of the Gold Deposits of Barkerville, B. C., and the Vicinity," *The Geological Magazine*, vol. III., 1906, p. 515.

the leaching of the silver content, for it is evident that the nuggets have been but little leached. There is no evidence that the placer gold is, as a rule, of greater fineness than the vein gold.

ACCRETION OF GOLD IN THE GRAVELS.

The view held by some writers, that nuggets are formed by the rolling together or welding of gold particles by the action of the stream gravels and the comparison which is made with the easy welding of gold in dentistry do not appear applicable, for, in order to secure good welding, it is necessary to use pure gold free from surface film. Placer gold is never pure and the particles usually have a surface film which would prevent welding. Moreover, the structure of the nuggets shows that they are not formed by the welding together of particles, but rather, by deposition from solution.

The formation of part of the placer gold by deposition from gold solutions in the gravels is possibly suggested by the occurrence of crystals and crystal groups, which are apparently too well formed to have been transported by the streams, by subangular and rounded pieces of quartz with thin platings or films of gold encasing them, and by the occurrence, in one of the hydraulic pits, of a rusty iron nail, to the side of which was firmly attached a small rounded piece of gold. In the latter case it is not certain that the gold was deposited from solution. What probably happened was that the piece of free gold was pressed or hammered against a roughened surface of oxidized iron, by the action of the stream gravels. On the other hand, the gold crystals are usually somewhat worn, and, as has been pointed out above, it is possible that gold crystals may have been derived from the oxidized parts of the quartz veins and included in the gravels without having been much worn. Fractured quartz cemented by gold may have been the source of the gold-plated pieces of quartz. The large accumulations of placer gold in places where the bedrock is favorable for retaining gold and around boulders, as pointed out by Atkin,[8] shows that the concentrations were the

[8] *Ibid.*, page 516.

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result of stream action. The comparatively rapid flow of the ground water, due to the steep gradients of the streams, is unfavorable for deposition of gold from solutions in the gravels. It is probable, therefore, that under present conditions little if any deposition of gold from solutions can take place in the gravels. It is possible that deposition from gold solutions in the gravels took place formerly, when the streams had low gradients and the rocks were deeply weathered, but this action was probably of little importance.

THE QUARTZ VEINS.

Two chief sets of quartz veins, which have been described [9] as the *A* veins and the *B* veins, occur in the district. The *A* veins consist of large bodies of almost barren white quartz with a prominent cross-vein jointing. These veins strike northwest and are sparsely mineralized with pyrite carrying low values in gold. The *B* set of veins strikes northeasterly and crosscuts the *A* set. They are predominantly narrow—from a fraction of an inch up to four or five feet in width—but there are many of them. In places they are closely spaced. They are usually well mineralized with galena, arsenopyrite, pyrite, and ankerite and carry in places some quantities of scheelite, sphalerite, and pyrrhotite. At the junctions of the two sets of veins there are usually developed shoots of sulphide minerals of considerable size.

The *A* veins occur in the "belt of veins" trending northwest and crossing the creeks near the upper limits of the rich placers. The shoots, therefore, are strung out intermittently along this belt where the *B* veins intersect it.

Some of the larger and more barren veins of the *A* class outcrop prominently along the valley slopes and on the grassy meadows of the upland. Most of the veins of the *B* class and all the mineralized intersections were found buried beneath drift. Veins of both types have been prospected for gold, but no shipping mines have been developed.

[9] "Quartz Veins of Barkerville Area, Cariboo District, B. C.," by W. L. Uglow, *Bull. Can. Inst. Min. and Met.*, Nov., 1922, pp. 1165–1175.

Free gold may be recovered by panning or rocking the upper disintegrated and oxidized parts of many of these veins. The veins in most cases are shattered and the sulphides are oxidized to various depths up to at least 50 feet. Free gold has been found only in this belt of weathering. In the zone of unaltered sulphides below, the gold content is contained almost entirely in arsenopyrite and pyrite.

Selective sampling of the sulphides in the veins showed that (1) as a general rule the galena is not auriferous but carries from one third to one half ounce of silver to the unit of lead; (2) the pyrite carries as high as $10.00 per ton in gold; and (3) the arsenopyrite carries gold in amounts varying up to 135 ounces per ton of pure mineral. The arsenopyrite in particular, therefore, is sufficiently auriferous to provide a possible source of gold for the placer deposits.

Character of the Vein Gold.—The vein or "quartz" gold, found in the oxidized parts of the sulphide-bearing veins, occurs in various sizes from very minute specks to pieces worth from $10.00 to $30.00.[10] The latter size is not necessarily the maximum, but represents the largest recorded piece of gold derived from the veins during the course of their limited development. A mass of gold worth 90 dollars is reported by mining men in the district to have been obtained from the Perkins ledge in the early days. It is possible that much larger pieces may occur. Most of the gold, however, is in small grains.

The gold exhibits, to a more or less perfect degree, a crystalline structure somewhat resembling a mosaic. Some specimens show a distinct granular structure due to the presence of a large number of minute gold crystals. The very fine gold is also crystalline.

Individual crystals and crystal groups are common. Some of the crystals are nearly perfect, the common forms being the dodecahedron, the cube, the cubo-octahedron, the octahedron, the cubo-dodecahedron and the tetrahexahedron. A small tetrahexahedron twinned on an octahedral face (spinel law) was found

[10] Macpherson, J. A., "Cariboo Placers and Lodes," *Mining and Engineering Record*, vol. XXIV., 1919, p. 128.

during the summer of 1922. Hopper-shaped faces indicative of rapid growth are common.

One crystal aggregate consisting of about a dozen dodecahedrons with hopper-shaped faces, having an arborescent arrangement and almost entirely enclosed in a mass of limonite, was obtained by the authors. The mass was about the size of a bean, and when found, only about three minute corners of the gold penetrated the envelope of limonite.

Hypidiomorphic crystals of gold are common. Angular pieces or fragments of quartz are frequently associated with the gold and much of the quartz is iron-stained. Spongy masses with a high degree of porosity are not uncommon, while many specimens consist of a fine-textured quartz-breccia, the fragments of which are held together by a cement or fracture-filling of gold. Leaf-like gold is also common, and appears under the microscope as if the leaves or flakes had just been removed from between walls of some other mineral whose rough fractures are preserved in relief on the sides of the leaves. Many of the pieces of gold have a fine columnar or wire structure apparently due to incipient crystallization.[11]

Origin of the Vein Gold.—The outstanding characteristics of the vein gold are (*a*) its occurrence in the form of leaves or veinlets—acting as cement in fractured quartz; (*b*) its occurrence as crystals; (*c*) its limitation to those portions of the veins characterized by limonite.

These characteristics definitely correlate the free gold with oxidizing conditions and with deposition in those parts of the veins which are highly fractured and cavernous. Well-developed crystals and crystal aggregates, such as that of the group of dodecahedrons mentioned above, could develop only in open spaces, or in spaces filled with the soft products of rock decay, where they had the opportunity of taking on definite bounding faces without interference from adjacent hard minerals. Vein-like gold, which is so common both by itself and as a cement in the

[11] Maclaren, J. M., "Gold, its Geological Occurrence and Geographical Distribution," London, 1908, p. 19.

quartz breccias, could have been formed only in zones of minute shattering of the quartz. Gold crystals and leaves or veinlets of gold may be formed in shear zones in quartz either near the surface or at considerable depths; but the limitation of the free gold to those parts of the veins in which limonite occurs confines the possibilities of such occurrences in this area to fractured zones at or near the surface. The free gold, therefore, has been formed by processes which operated under conditions of oxidation near the surface.

The hypothesis which is here advocated as an explanation of the occurrence of the free gold is that the gold content of the unoxidized parts of the veins was and still is largely, if not entirely, confined to the sulphides, mainly arsenopyrite and pyrite; that the oxidation of these sulphides under near-surface conditions released the gold which passed into solution only to be precipitated in crystal and leaf form at short distances below in the belts of weathering and cementation.

The conditions necessary for the operation of such processes and for production of sufficient free gold in the veins to supply the placers would be (1) deep weathering and disintegration of the veins and country rock, (2) the presence of solvents and precipitants for gold, and (3) sluggish transportation by the streams. These conditions are fulfilled in the Barkerville area, which consists of a deeply dissected high-level plateau, the uplands being composed of remnants of a plain-like surface of erosion. Streams which formerly flowed at or somewhat below this plateau level must have been sluggish, for they occupied broad shallow valleys. The amount of material being carried by the streams was therefore small, and rock decomposition with solution of the constituents must have been the most important feature of the later phases of that cycle of erosion.

There is little definite information available concerning the agents of solution and precipitation of the gold in the veins of this area but it is certain that this action has taken place. As shown

by Emmons,[12] Brokaw,[13] and others, chlorine in the nascent state is a most important and efficient solvent of gold. Chlorine-bearing minerals have not been recognized in the veins, and there seems to be no reason for suspecting their presence. Except for the possibility of the presence of chlor-apatite in the schists, quartzites and dike rocks of the area, the only other sources of chlorine that might be available would be the rain water, or salt (NaCl) derived from the limestones of either sedimentary series. Oxidation of the pyrite and arsenopyrite would afford a supply of sulphuric acid which is essential to the solution of gold. Manganiferous carbonate, which on oxidation affords manganese dioxide, an important agency in the solution of gold, occurs abundantly in the veins. In this connection, it is interesting to note that on Burns Mountains near Stanley, from which the largest recorded pieces of quartz gold have been derived, a deposit of bog manganese was found from which a random sample gave on analysis 21.7 per cent. manganese. This manganese was no doubt derived from the alteration of the carbonates.

Minute quantities of the above-mentioned constituents might produce solvents for gold in amounts large enough to produce the results that have been accomplished, when it is noted that these changes occupied a long period of time during which the country was being reduced to a plain. Semi-arid conditions, as is possibly indicated by the general absence of wood in the ancient gravels, would also be favorable for gold enrichment, as they would permit of deep weathering and a marked oscillation of the ground-water level.

Agents for the precipitation of the gold are abundantly present in the form of pyrite, ankerite, and carbonaceous material in the veins. According to Brokaw[14] the carbonates, calcite, siderite, and rhodochrosite, rapidly precipitate gold from chloride solu-

[12] Emmons, W. H., "The Enrichment of Ore Deposits," U. S. G. S., Bull. 625, 1917, pp. 305–308.

[13] Brokaw, A. D., "The Solution of Gold in the Surface Alterations of Ore Bodies," *Jour. Geol.*, vol. 18, 1910, pp. 321–326.

[14] Brokaw, A. D., "The Secondary Precipitation of Gold in Ore Bodies," *Jour. Geol.*, vol. 21, 1913, p. 256.

tions, while Emmons[15] states that "siderite is particularly efficient probably because in acid, abundant ferrous sulphate forms."

The gold is found under conditions which suggest that both ankerite and pyrite were its precipitants. Several pieces of vein gold (and placer gold as well) show negative pseudomorphs of pyrite or cubical depressions from which the iron sulphide has been leached. Much fine gold occurs in the porous honeycombed quartz from which pyrite has been removed, and specimens of the quartz from Burns Mountain were seen by the writers from which finely crystalline gold could be removed by shaking or tapping the specimen.[16] Both of these cases are illustrations of the efficacy of pyrite as a precipitant of gold from solution in this area. Gold has also been found associated with the characteristic rusty negative casts left by the solution of ankerite.

The occurrence of free gold (1) as fine crystalline dust in the negative casts of pyrite crystals and in the rusty fractures near the surface; (2) as cement in fractured quartz; and (3) as fairly large crystals and crystal groups, throws some light on the manner of its growth. These three types of gold are crystalline, and show distinct evidence of having been deposited from solution. No evidence has yet been found to indicate the condition in which gold exists in the sulphides—whether in the native form as very fine disseminations, in chemical combination or in solid solution; but the fact that wherever found it is either in actual crystal forms or with a crystalline structure indicates strongly that it must occur in the sulphides in a state in which, on the removal of the sulphides, it is readily subject to solution from which it is later deposited.[17] The gradations in size which occur between the fine free gold and masses weighing 1½ ounces or more from Burns Mountain, suggest continuous growth of the gold by the addition of material from gold solutions. The occurrence of the

[15] Emmons, W. H., *op. cit.*, p. 311.

[16] Rickard, T. A., cites a similar case in "The Formation of Bonanzas in the Upper Portions of Gold-veins," Genesis of Ore Deposits, A. I. M. E., 1901, p. 737.

[17] In this connection certain experiments by Liversidge are interesting, in which he produced filaments of gold simulating moss and tree gold by roasting auriferous mispickel; *Proc. Roy. Soc., N.S.W.*, Vol. XXVII, 1893, p. 1.

cement gold is undoubted proof of the operation of the processes of solution and deposition of gold ending with the healing of the fractures. Where a rich supply of gold in its original form, as in some of the arsenopyrite, is available, there seems to be no reason why the continuous oxidation of the arsenopyrite and the removal of part of the gold in solution should not result in the gradual growth of fairly large single masses of cement gold.

A satisfactory hypothesis of the origin of large crystalline masses and definite crystals of gold in the veins is based on the reasonable assumption that the main part of the enrichment took place prior to peneplanation, while the country was still somewhat rugged and semi-arid. Under these conditions the belt of oxidation above the ground-water table would have had a considerable vertical extent, perhaps 100 feet or even more. On the oxidation of the sulphides and the solution of the carbonates, solvents would be provided for the fine gold. This gold, once in solution, would travel downwards until reducing conditions were met with at the level of ground-water or beneath it, and there would be deposited in crystalline form. Such conditions would provide a relatively thick gathering ground for the gold solvents, and, on the other hand, a restricted locality in which deposition would take place. Were the level of the ground-water table to remain constant until all the gold were leached from the suggested thickness of 100 feet above the water table, the result would be the deposition of all of this gold in a shallow horizontal belt near the water level. During this process of deposition large crystals, groups and veinlets would develop by gradual accretion. The progressive lowering of the water table with the reduction of the relief of the country would bring lower and lower portions of the sulphide zone into the belt of oxidation and release its content of gold. As the larger pieces of this secondarily deposited gold came within reach of surface erosive agencies through the mechanical removal by drainage of the oxidized overburden, they gravitated into the valleys of the early Tertiary streams, there to form the first placers, which have since been worked over and concentrated to form the placers that occur in the bottoms of the deep V-shaped valleys of post-peneplain time.

RELATIONSHIP OF THE PLACER TO THE VEIN GOLD.

The occurrence of large amounts of coarse, nuggety gold, gold crystals, and mammillary gold in the placers and the apparent general absence of coarse gold in the auriferous veins of the Barkerville area appear to be the main difficulties in the way of accepting the view that the placer gold is detrital in origin and was derived from the oxidation of the sulphides in the veins. It is held, however, that these difficulties are overcome by a consideration of the facts set forth above and here summarized.

During the long period in Tertiary and possibly also in late Cretaceous times when the country was being gradually reduced to a nearly plain-like surface of erosion, oxidation of the sulphides of the quartz veins and gold enrichment in the upper oxidized parts of the veins must have taken place on a fairly large scale.

The comparatively narrow and deep V-shaped valleys, in which the rich placer gold has been mined, show that the old plain-like surface was later uplifted and dissected by streams. The free gold of the Tertiary bonanzas was gradually washed down into their beds and during the gravitation downward of the angular, crystal, and leaf gold of the veins, the corners and edges became rounded, the sharp points and other protuberances were bent, the enclosed quartz was gradually removed, and silver was selectively leached from the peripheries of the grains. Many of the nuggets of the gravels were derived in this way.

The placer gold as well as the vein gold is crystalline and in both cases there is evidence that it was formed by a process of gradual accretion from gold solutions. Masses of the gold thus deposited in the vicinity of the water table in the veins, and only slightly modified subsequently by the action of the streams, are found in the placers. They probably owe their irregular outline to the shape of the cavities in which they were formed.

Gold crystals occur in the oxidized parts of the veins as well as in the placers. Those found in the placers are usually somewhat worn. It is therefore improbable that they are formed in the gravels.

The apparent general absence of coarse gold in the exposed

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parts of the veins may be explained partly in one way and partly in another. From the relatively insignificant amount of lode mining, resulting in the recovery of only a few thousand dollars worth of gold, specimens of free gold of a maximum weight of at least 1½ ounces have been found. From the mining of at least thirty millions of dollars of placer gold, representing the concentration from the wearing away of a great thickness of the country rock and veins, there is said to have been obtained only one or two nuggets above thirty ounces in weight. Lack of exploration of the ledges, therefore, may be partly the reason for the failure to find any but small amounts of coarse quartz gold. During the time when the country was being reduced to a plain, conditions were probably very favorable for gold enrichment in the upper parts of the veins. The gold thus formed and released by weathering gravitated into the old valleys in the plain. Rejuvenation of the streams by uplift caused a further concentration in valleys, which coincided nearly with the ancient valleys. This concentration has produced the present placers. The free gold in the outcrops on the plateau represents the roots of the ancient enriched zone, the upper parts of which were removed to the streams. Most of the vein enrichments which produced coarse gold in the past have thus undergone two concentrations in the stream beds, leaving only a small part of these enrichments for exploration today. Ice-erosion during Pleistocene time also removed parts of the enriched zone. It is, therefore, not to be expected that the present outcrops of the veins would be as rich in free gold as were the ancient outcrops. There is every reason to suppose that, if the oxidized parts of the veins could have been examined before the plain-like surface of the region was uplifted and dissected, rich bonanzas of free gold would have been encountered.

GEOLOGICAL SURVEY,
OTTAWA, CANADA.

MAGNETIC SURVEYING ON THE COPPER-BEARING ROCKS OF WISCONSIN.[1]

H. R. ALDRICH.[2]

INTRODUCTION.

THE writer and assistants devoted the field season of 1922 to surveying with magnetic instruments an area of about 180 square miles in northern Wisconsin. The country rocks here are the Middle Keweenawan formations which in Michigan are being worked for copper. Glacial deposits are heavy and consequently exposures of ledge are few and small although probably the situation is not far different from that on Keweenaw Point. On account of this condition the geology is generalized from scanty data. Even the boundaries between Middle and Upper Keweenawan divisions and between Middle Keweenawan and the older rocks are not accurately known. And the drawing of internal boundaries between the individual members of the Middle Keweenawan series has been previously attempted only in limited areas where exposures give some idea as to their location.

The main purpose of the work was to see if the magnetic methods which have been used by this Survey during the past ten years primarily in the search for iron formations would be of assistance in locating formation boundaries and in determining the structure of the copper-bearing basic lava flows.

For two reasons further knowledge of these Keweenawan formations is desirable; the first is economic. Copper has long been known to exist here and it is advisable to know if the geological conditions may indicate possibility of commercial ore. The second reason is that these formations contain the record of the development of the Lake Superior basin structure and that record

[1] Presented before the Society of Economic Geologists, Ann Arbor Meeting, December, 1922, as a part of the symposium on Michigan Copper Deposits.

[2] Introduced by W. O. Hotchkiss.

must be read before we can hope to solve the problems of the copper and iron bearing rocks.

In applying magnetic methods it is granted that they will tell little directly about the quantitative rock composition and nothing about the copper content. They will, however, afford a means for determining all those space properties such as dip, strike, curvature through folding, or dislocation through faulting, or, in short, the establishment of external and internal boundaries.

The purpose of this paper is to present briefly the present general knowledge of the Middle Keweenawan in Wisconsin, some of the results obtained during the past summer by mapping in detail with magnetic instruments, and a brief statement of the copper possibilities of the region

THE MIDDLE KEWEENAWAN.

The latest geological map of Wisconsin shows an area of about 2,400 square miles over which Middle Keweenawan rocks are believed to be distributed at the surface or under the drift. This area is continuous but has an irregular shape which is determined by structure.

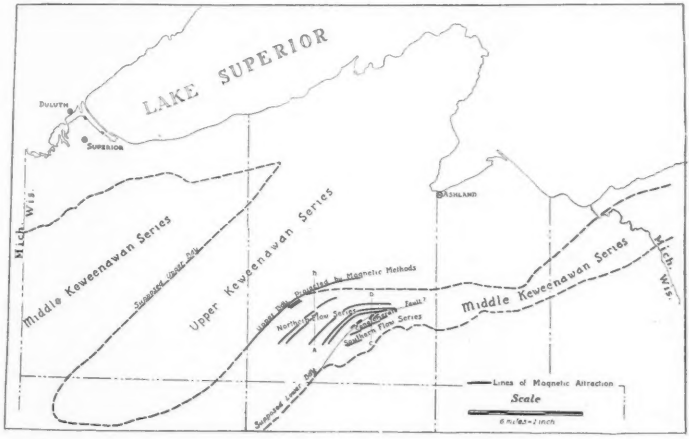

FIG. 75. Showing distribution of Keweenawan series and magnetic lines traced. AB and CD are locations of magnetic profiles shown in Fig. 76.

The principal axis of the Lake Superior syncline lies north of Keweenaw Point and is approximately parallel to the south shore of the lake as far as the head of Chaquamegon Bay where it cuts onto the land. From here it turns more to the southwest and continues across Wisconsin and into Minnesota. Since the formation of the syncline, erosion has planed down the flanks of the fold. The north-dipping south limb of the syncline forms a belt that varies in width from about four to thirteen miles. The variation is accounted for chiefly by change in dip but partly by thickening and thinning of the series. (See Fig. 75.)

About 70 miles southwest of the head of Chaquamegon Bay the nose of the trough of the contact between Upper and Middle Keweenawan comes to the surface and the belt just described widens with the structure. With the reverse of the dip to the southward on the north limb the area expands. The dip is more gentle than on the south limb, a thrust fault of nearly east-west strike cuts across the strike of the beds giving to this area a roughly triangular shape.

The formations in the series comprise melaphyres and porphyrites with felsitic flows and conglomerates that are identical with those on Keweenaw Point. In the upper horizons sediments become increasingly abundant. On the south limb of the syncline there is a thick coarse-grained gabbro mass which is intrusive as a laccolith into the lower horizons of the series.

Copper occurs at many points throughout the area both in the metallic state and sulphides. From the observations made during the one season's work it appears that the sulphides are more abundant close to the gabbro intrusive. This may possibly be explained by the fact that exposures are also more abundant near the gabbro.

This brief sketch portrays in a general manner what is known in regard to the areal distribution, structure, and subdivisions of the series. The absolute identity of these formations in Wisconsin with those of Michigan has long been established.

RESULTS BY MAGNETIC METHODS.

Application of Magnetic Methods to Igneous Rocks.—The dip needle is best known in the Lake Superior region for its use in searching for iron formation and the Wisconsin Survey originally used it primarily for that purpose. Areas were mapped whose magnetic attraction was so comparable to that of known iron formation that they were recommended for drilling, but the drilling showed that igneous rocks were in most cases responsible for the attraction. This was an unintentional application of magnetic methods to the field mapping of igneous rocks.

In subsequent years, while working in driftless areas the Survey had a chance to "feel out" various types of igneous rocks with magnetic methods and found that they could be followed.

Seven years ago while working on the Huronian iron formation of the Western Gogebic Range the Survey made a hurried test of the applicability of the methods to the Keweenawan flows. The results gave considerable promise. During the past field season a party was maintained on a more thorough test of the methods on the north-dipping south limb of the syncline.

General Procedure.—The first step taken in the recent work was to run four north-south lines across the belt known to be underlain by the formations, taking readings on the magnetic instruments at intervals of twenty-five paces. These lines were two miles apart and about nine miles long. A scaled map was then constructed on which the dip needle readings were plotted in the same manner that a topographic profile is made.

The four magnetic profiles were then studied and compared. Points of similar attraction were found to lie upon lines parallel to one another, or which departed from parallelism at a constant rate due to a change in dip of the formation, or which formed two groups within which these relationships held, but which as groups converged in strike.

Determination of External Boundaries.—The first points of similarity on the north lay upon a smooth curve along which the dip needle showed the change from absence to presence of local attraction. This line of similarity was correlated with the contact

between the magnetic flows and the overlying non-magnetic sandstones and conglomerates, the contact between the Middle and Upper divisions. It could readily be tested for continuity by crossing the line at more frequent intervals. This was not actually done at this particular place, but farther west it was traced in detail, and the boundary so established was checked by means of outcrops and drill records. The boundary thus established lies more than a mile north of the boundary as it appears on the latest maps, and consequently the area of the series was shown to be larger by several square miles than had been thought previously.

Similarly the lower boundary may also be determined at any particular point, although there are irregularities along this horizon which make the boundary much more difficult to trace.

Determination of Internal Boundaries.—A second series of points of outstanding similarity lay upon a line about 2 miles south of the north boundary and parallel to it. This was carefully traced through a distance of twelve to fifteen miles and probably can still be followed at either end.

The points of similarity are not necessarily points of maximum attraction. Points of minimum (subnormal) attraction were also noted. In the most outstanding case the similarity consisted, not in a single point but in a group which was followed as a belt. This group is made up of a narrow belt of subnormal attraction on the north, followed by a series of closely spaced maxima and minima, and a belt of normal attraction on the south.

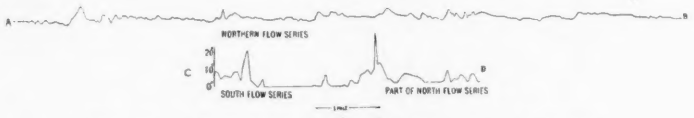

FIG. 76. Magnetic profiles (see Fig. 75 for locations).

Any one of the long profiles can be likened to the teeth of a rip saw with the more gentle slopes of the teeth inclined toward the direction of dip. (See Fig. 76.) Of course there is no such regularity as this comparison might suggest, for on the major

"teeth" there are minor cusps. Many of the minor features are, however, local characteristics as is indicated by the fact that they differ on the adjacent profiles and as proven by the failure of our attempts to trace a continuous line of the same sort of magnetic reaction through such points. Experience showed that the best procedure was to run profiles at half mile intervals and after plotting, to construct a smooth curve through the points on the profiles. Then the broader features, maxima, minima, or points of inflection, were satisfactorily traced and showed absolute continuity.

When such lines of similarity were plotted on the map and the exposures that had been located with respect to them were also indicated, these exposures were automatically correlated with the belts of similar attraction, and those of the same horizon were then studied as a group. Without such a scheme very few of these exposures could be correlated because the intervening distance is too great and the lithological properties of exposures belonging to different flows are too nearly alike.

Of course this method does not correlate say three outcrops two miles apart as portions of the same *individual flow*. As a matter of fact we found that it was difficult to trace continuous lines of attraction at the more closely spaced intervals in order to prove that exposures belonged to the same particular flow. Hence we do not feel that we have traced every individual flow. The prominent "teeth" on our saw tooth profiles through which the most continuous lines of attraction may be traced are so spaced that the resulting lines are of the order of 4,000 feet apart. Figuring stratigraphic thickness of the formation between two such lines with a dip of 30° gives 2,000 feet. No exposure that we have found, nothing we have seen in drill core or in the Michigan mines, has discounted our belief that the 2,000 feet of formation is not one single flow. We believe that such thicknesses represent groups of flows within which there are close compositional relationships.

In order to explain some of our interpretations of these magnetic observations, it is necessary to include here some of our theoretical views.

Our "saw tooth" magnetic profiles show prominent recurring maxima with subordinate cusps. Stripped of all the modifying effects of variation in drift thickness and preglacial topography the meaning of these high attractions is maximum concentration of magnetite. In flows such as these the top or the bottom or both are the places for magnetite concentration.

Since high attraction is found continuously along lines passing through the more prominent teeth on the profiles, we have concluded that such lines mark the surface trace of the tops or bottoms of flows. As these lines are 2,000 feet or more apart, they cannot mark single flows. From outcrops we know that many flows make up each one of these belts and from magnetic profiles there are indications that between lines of heaviest and continuous attraction there are less prominent and seemingly less continuous lines of attraction. We have speculated a good deal on the fundamental meaning of these heavy and continuous concentrations of magnetite occurring at more or less regular intervals and the subordinate less continuous concentrations.

Extrusion was not continuous. A flow was extruded and a period of rest followed. This is the shortest cycle of extrusion. The interpretation I have put on these "saw toothed" magnetic profiles is that there were greater cycles that included many flows —that there were periods when flow followed flow with relative rapidity, and other periods when there were long pauses between flows, and that these caused our "saw toothed" distribution of magnetite. In the longer pauses differentiation would take place in the magma reservoir and the new cycle of flows could in this way differ widely from immediately preceding flows in magnetite content.

Our final magnetic map showed that a number of belts, some a quarter of a mile wide, some a half mile wide, some more nearly three quarters of a mile wide, were formed by the tracing of the lines of magnetic attraction. It is obvious, however, that much greater detail can be obtained by tracing some of the less continuous lines of attraction.

Determination of Structure.—The most striking development

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on the map consisted in a certain group of parallel or nearly parallel lines of attraction, representing the surface traces of beveled flows which converged in strike, with lines and belts to the northward that are "through lines" continuous for many miles beyond the points of apparent convergence. Furthermore, there are a sufficient number of outcrops within the confines of both of these groups of lines to establish the fact that these separate groups of formations converge in dip as well as in strike. Between these two groups of non-conformable basic flows there is a thick mass of acidic conglomerate with intercalated felsite and diabase flows. The amount of divergence in strike and dip can be gathered from the fact that the northern series strikes nearly east-west and dips vertically and the southern series strikes about N. 70 ° E. and dips about 50 ° NW. The west extension of the northern series swings gradually into a N 45 E. strike and dip of 25 ° NW. although the southern series maintains its strike N. 70 ° E. as determined by the lines of attraction.

There are two possible interpretations of this situation. The first is that the two series are unconformable and the plane of unconformity is an erosion surface lying on the conglomerate. The second is that the unconformity is a fault plane which coincides in strike at least with the strike of the upper series. While both ideas are considered as possibilities, the fault possibility is favored. At about the point of intersection in strike on the east there is a gabbro intrusive whose field relationships suggest laccolithic nature. We have yet to discover what the relationship of this gabbro mass to the unconformity may be.

The Conglomerate.—The conglomerate which was referred to above because of its position just below the unconformity appears to have unusual thickness and is worthy of note for that reason alone. In one outcrop a good exposure of the contact between the conglomerate and a rhyolite porphyry flow was found so that we were able to construct a much clearer mental picture of the conditions of deposition than had been sketched before from all other exposures.

This conglomerate is very similar to the Calumet conglomerate

at Calumet, Michigan. The dominant rock represented in the component pebbles, cobbles, and bowlders is a pink rhyolite porphyry. Acidic rocks of variable texture, color, and all apparently of surface occurrence make up probably more than 90 per cent. of the sediment. Basalts and diabases and porphyries make up the remainder.

The sizes range from a fine sand to bowlders four and five feet in diameter. Shapes also have a wide range and although there are no sharp corners or edges, the amount of rounding falls far short of giving these pebbles and bowlders any close approximation of sphericty. Of course coming as they do from extrusives which may very well have had a strong tendency to break into tabular fragments, the lack of spherical shape must not be carried too far towards the conclusion that these pebbles have not been greatly water worn. Furthermore, we have reason to believe that an arid climate prevailed during this period and rupture due to differential expansion, which also produces tabular pieces, probably was an active process in the disintegration of the surface flows.

The conglomerate is poorly assorted. Whenever dip and strike were determined, it was upon thin beds of finer debris. Even in the finer material the size of pebbles varies widely. Furthermore, the exposures show cross bedding on a large scale and yet no constant direction of currents could be found. It was our impression, however, that there was a slight prevalence of currents from down the dip and therefore, before tilting, from the north.

The most instructive exposure found showed rhyolite and conglomerate in such relationships that the rhyolite can be considered only as an extrusive. The strike and dip of the conglomerate is parallel to the upper surface of the flow. This contact may be followed at least one hundred and fifty feet. On the west the contact takes a nearly right angled turn toward the foot showing that the conglomerate forms a nearly perpendicular wall which limited the flow in that direction. As closely as could be determined the trend of this wall down the plane of dip is in the general north-south direction. The flow is at least fifty feet thick and may be considerably thicker, but the lower contact is concealed.

Along the upper side of the flow and down the wall on the west are flow lines in the rhyolite. These are not regular over any considerable area, in fact they take broad sweeping curves and close turns that suggest a considerable amount of working in the viscous mass. Close to the conglomerate they are roughly parallel to the contact.

The conglomerate forming the west wall and that which overlies the rhyolite is composed largely of felsites which are similar in nature but not identical with the flow. Coarse and fine beds alternate rather frequently.

Interpreting these observations we picture a semi-arid region containing mountains or at least high elevations at the foot of which were deposited coarse, poorly classified bowlder washes. Torrential streams with tremendous carrying power carried this heterogeneous collection of debris off the high ground to the fans, spreading the material widely, but in places cutting steep-walled gulches. The general situation was much as obtains today in semi-arid regions of the West. Down these gulches extrusive rhyolite flowed.

The difficulty that is met in studying the conglomerates is to account for an adequate source for the acid debris. Lane has shown graphically that the volume of the acid flows that are known in Black River Section falls considerably short of the volume of the acid rocks in the conglomerate. In the outcrop just described there is a rhyolite flow interbedded with the conglomerate and here (but especially elsewhere in this vicinity) the conglomerates that overlie rhyolite flows carry in the immediately overlying strata a very considerable quantity of rhyolite which is apparently identical with the flow. This would indicate that much of the rhyolite in conglomerates was derived from contemporaneous flows. And the indication that the bowlder movement was from the north would necessitate the view that acidic flows were present down the present dip or up the original slope. If our conclusions are correct that the conglomerates were deposited at the base of steep downward slopes to the south, then the acid flows must have come from the same

direction. This means that the source of acid extrusives lies down the dip, or before tilting, to the north. The deficiency in acid material which Lane has pointed out may be readily accounted for in such a view.

Our conclusions reached at least tentatively are that this was a land deposition in a region over which acid extrusives were contemporaneously poured. Mechanical disintegration practically alone produced the pebbles, and streams of vigorous power transported them rapidly down steep slopes but through no great distance.

While further study is required, the representations of climate, topography, and general conditions of igneous activity and sedimentation seen in these conglomerate exposures fit in well with a more general idea of Keweenawan physiographic and climatic conditions based on other observations.

COMPARISON OF OBSERVATIONS IN WISCONSIN AND MICHIGAN.

The writer spent several days underground in Michigan with Messers. Graton, Butler, and their associates and found that there is a close identity between rocks, structures, and general conditions in Michigan and Wisconsin. The igneous formations appear to be identical mineralogically and texturally. The extrusives have the same kind of tops, cellular or brecciated. The smooth tops and rough tops in Wisconsin are identical with those in Keweenaw Point. There is reddening in the tops in many cases. No close study has yet been made of the mineral associations with respect to which a comparison can be made, but no glaring discrepancies exist and no minor ones have been detected.

The conglomerates are in general identical although the one described most fully is probably much thicker than anything known on Keweenaw Point.

Furthermore there is copper in the Wisconsin rocks and its occurrence seems to be identical with that in Michigan, but whether copper will ever be produced in Wisconsin from the Michigan-type of deposit is a consideration of the future. At present there is considerable encouragement in the general agreement with all

the features which we understand have been found to be significant in Michigan.

The most striking contrast between Keweenaw Point and our Wisconsin area—one that may have an important bearing upon the question of copper mineralization—is the difference in location of the two with respect to the axis of the Lake Superior syncline. We of this Survey find many strong indications that the location of the fissures through which the lavas welled was along the present axis of the syncline. This axis plunges northeastward. Consequently the Keweenaw Point area is farther from the axis than some parts of the Wisconsin area.

If then, the new theory of mineralization proposed by Mr. Graton and associates is correct and if the ultimate source of the copper-bearing solutions is in the same fissure as that through which the lavas welled, as the theory suggests, the degree of copper deposition may have a relation to the distance from the vent. If the intensity varies directly as this distance, the Wisconsin rocks may lie too near the source to have induced deposition in quantity. In other words, if mineralization produced zones and the Keweenaw Point deposits mark the location of the most intense deposition, the projection of that zone parallel to the vent would have passed through some of the rocks in the Wisconsin area that have been removed by erosion.

CONCLUSION AND SUMMARY.

Our work in Wisconsin will proceed along the lines followed during the past season. We aim to follow up the apparent unconformity, to study the gabbro intrusion, and continue lines of subdivision of the series, all in conjunction with an intensive study of the existing meager exposures.

The work of Messrs. Graton and Butler will create added interest in the Keweenawan copper-bearing rocks of the Lake Superior region. We have undertaken a study of the series in Wisconsin, but the formations of this age practically surround the lake, and it is not at all unlikely that they will be studied more in detail in the future.

It may very well be imagined that the papers read by Messrs.

Graton and Butler will give rise to the questions: "What bearing does this theory have upon the chances that unexplored ground carries ore bodies? How do these areas look in the light of these new ideas?" The areas away from Keweenaw Point may perhaps at once come in for new examination, but we feel that if not at present the attention will come within a very few years.

The Wisconsin ranges have been examined by geologists and they have been drilled by exploration companies. By some they have been condemned, by others they have been held in suspended judgment, and from others the admission has come that possibilities are good. But when it is considered that the ratio of the area of the exposure to the area underlain by the series is somewhere of the order of 1:100,000 and that glacial cover is present to a depth varying from nothing to 200 feet, it will be agreed that at present no one has possession of sufficient data to pass final judgment.

Then the question comes, if the exposures are so meager and if the drift cover is so deep that geologists in the past have not been able to obtain the data necessary for a final conclusive opinion, what can a geologist do in such an area? So far as a thorough examination and testing of the rock is concerned, we of the Survey fully agree that ordinary methods hold out little hope for an immediate solution of the problem. But we believe that there is much that may be done on the surface by means of a magnetic survey that will aid campaigns for the systematic disclosure of what lies below the drift.

The writer has aimed in this paper to show how a magnetic survey will be of assistance in tracing the series and its subdivisions. The copper-bearing series is there in force, it bears copper in interesting quantities, and furthermore, so far we have knowledge of the conditions in the lodes of Michigan and of the prime factors of the new theory, the Wisconsin rocks are identical. We therefore feel that the interest of explorers which must sooner or later turn toward Wisconsin will be fully justified.

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SIMILAR, PARALLEL AND NEUTRAL SURFACE TYPES OF FOLDING.

E. L. ICKES.

THE object of this paper is to present some of the features of three simple types of folds, two of which are often mentioned in oil geology. So far as the writer is aware some of the matters discussed have not heretofore been mentioned in the literature, at least not in references usually consulted by the petroleum geologist, and should it transpire that those parts have appeared elsewhere the writer believes he will notwithstanding have the satisfaction of bringing to the attention of the oil geologist certain features of folding to which he has not had ready access in the literature. The deformation of a horizontal series of strata into a folded zone implies that the superficial area occupied by the horizontal rocks originally has been reduced by the folding. This entails a shortening of the earth's crust and the calling into play of forces more or less tangential in direction. The fold induced by the intrusion of a laccolith or the growth of a salt core

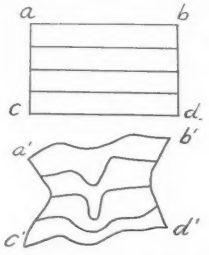

FIG. 77. General case of deformation.

would not in general indicate a shortening of the crust or tangential forces, and this type of fold is not discussed in the following pages. In Fig. 77, *abcd* represents the original block of hori-

zontal strata, which after folding emerges as $a'b'c'd'$. On the assumption of no change of density due to the folding, the volumes in both cases would remain the same. The conditions represented in the figure are of a more complicated type than is discussed herein, the irregularities of the folds and boundaries $a'c'$ and $b'd'$ indicating unequal pressures and resistances distributed along the boundaries. For this paper the simplest condition possible is taken, namely that in which the ends $a'c'$ and $b'd'$ emerge from the folding as straight and parallel surfaces. This simple ideal condition while probably not existing in nature may in fact be a close approximation to the folding conditions in many of the oil fields where the deformation is not excessive. For further simplicity the folds are discussed in two dimensions which implies that we are dealing with forces which are constant along the faces perpendicular to the plane of the paper and that the faces parallel to the paper are always the same distance apart. Neither this condition nor the condition of parallel ends exists on any scale in nature, but it is believed are sufficiently close to warrant a discussion with these limitations in mind.

SIMILAR FOLDS.

The simplest types of similar folds are shown in Fig. 78. If certain thin beds making up these folds were to be taken and laid side by side in a horizontal row they would form an even surface similar in shape to any one of the layers. If now the beds are built back into a fold, this can be done in two simple ways:

(a) By raising each layer so that there is a constant vertical distance between it and the one below, which is the Rectangular Type of Fig. 78.

(b) By raising each lamina in an oblique direction such that the oblique distance between any two beds is everywhere the same, which is the Oblique Type of Fig. 78.

If we refer (a) to a set of rectangular coördinate axes and (b) to a set of oblique axes, it is evident that the distance parallel to the ordinate OY is everywhere the same between two beds.

Similar folds of these types if occurring in nature and not overturned would have the following characteristics:

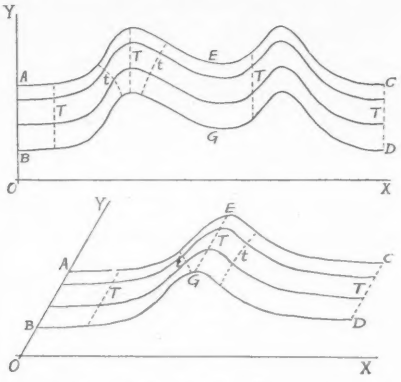

FIG. 78. Types of simple similar folds. Upper, the rectangular; lower, the oblique.

1. They would persist with depth.

2. The ends AB and CD are parallel planes which are parallel to the ordinate OY and to the axial planes of the anticlines and synclines. The length between two ordinates of any two beds is the same, such as $AEC = BGD$. The dip along any ordinate is constant from top to bottom of the fold.

3. The conditions of similar folding imply crustal shortening under the action of tangential forces.

4. The original unfolded block whose deformation has resulted in a system of similar folds of the type under discussion, had a length L and a uniform thickness T_0. After the folding the block has been reduced to a length a, which is the horizontal projection of L; and the crustal shortening is measured by $L—a$. Calling the ordinate distance between the top and bottom of the fold T, the volume of the fold[1] is now represented by Ta, where T is a constant value throughout the region so folded. On the assumption of no change in volume during folding, by equating

[1] The discussion in paragraphs 4 and 5 is limited to the rectangular type.

the two values we find that $T = T_0 L/a$. If the crustal shortening is small T and T_0 are practically the same. The thickness usually determined in field work is that perpendicular to the dip, and this we shall refer to as t, the apparent thickness, which takes the form of an orthogonal curve. Evidently t is a variable, increasing from a minimum on the steep flanks to a maximum T on the axes of folds.

It should be pointed out that in determining thicknesses in regions of similar folds the value sought for should be T, the ordinate thickness, rather than t, the apparent thickness. The latter is a measure of the degree of deformation, while the former approximates the original or true thickness T_0.

5. The occurrence of frictional heat due to folding is of interest to geologists in its bearing on the generation, alteration and migration of oil in the beds. We will endeavor to arrive at some idea of the heat distribution in the case of the simple folds under discussion. Taking the x-axis as the horizontal projection of the folded strata, an elementary volume from top to bottom of the bed may be represented by $dV = T\,dx$. Originally this volume in the unfolded beds had a value $dV_0 = T_0 dL$, so that the change due to folding is $T\,dx - T_0 dL = du$, say. Since $T = T_0\,L/a$, and $dx/dL = \cos\phi$, where ϕ is the angle of dip, this equation becomes

$$du/dx = T_0\,(L/a - 1/\cos\phi),$$

which gives the rate of volume change along the x-axis. This shows that along the ordinate where the dip has the value $\phi = \cos^{-1} a/L$ the rate of change is zero, which means that for a short width aong this ordinate the original volume has not been changed by the folding although flow of material from the flank has passed through the section. On the flank side of this critical dip the rate of change is negative, while on the crest side it is positive. The critical dip occurs at every point in the folded region where the angle has the above value and would normally occur on each flank of an anticline and syncline. The negative value of du/dx on the flank side of the critical dip indicates

squeezing or attenuation of the beds, while the positive value on the crest side indicates expansion.

The zones of squeezing and expansion can be seen by referring to Figs. 78 and 85. The constant ordinate thickness T is always greater than the true thickness T_0 and the variable apparent thickness t approaches in value T_0 in the vicinity of the critical dip. The expansion in volume in the crests is due to inflow of material squeezed out from the flanks.

As regards the distribution of frictional heat, it would appear by inspection that the greatest amount would be expected on the flanks in the zones of squeezing, where the greatest shearing and flow per unit area of cross-section have been in operation. In confirmation of this view the following is presented: it is a reasonable assumption to refer the total work expended in deforming the region as proportional, in part at least, to the crustal shortening, $L - a$. From this we infer that an element of work along any ordinate is $dW = k\ (dL - dx)$ where k is a constant. If the frictional heat H is itself proportional to the work done then the variation in heat produced along the x-axis is expressed as $dH/dx = A\ (dL/dx - 1) = A\ (1/\cos \phi - 1)$, where A is a constant. This implies that the frictional heat increases with the dip, being zero on the axes of folds and infinity where the dip is vertical, or more heat is produced in the zones of squeezing on the flanks than in the crests or troughs.

The writer does not believe the above analysis to be precise, since heat must have been produced in the fold axes in increasing the true thickness T_0 to the ordinate thickness T, while the difference in physical conditions implied by the zones of squeezing and expansion probably has a bearing on the question.

6. Various thin layers in a similar fold may be under parallel or neutral surface conditions, as will be pointed out later.

7. Similar folding should offer interesting points of attack by the mathematician, for two simple relationships exist, namely the constancy of dip along an ordinate, and the relation connecting the equations of any two beds. For if $y = F\ (x)$ be the equation of one bed, that of any adjoining stratum at constant inter-

val T is $y = F(x) + T$. It would be helpful to geologists if mathematicians would make use of these facts or any others in this paper towards determining the nature and direction of the resultant stress at any point in a fold.

PARALLEL FOLDS.

This type is commonly used as the basis for computing formation thickness from observed dips the assumption being that the strata in such a fold are in parallel curves and that the dip is constant along a line at right angles to any observed dip. The perpendicular line measures the thickness between two beds which is constant and represents the true thickness, there being no apparent thickness as in the other two types of folding under discussion.

To examine the conditions requisite for parallel folding let *abgh* in Fig. 79 be folded along the arc of a circle of radius r

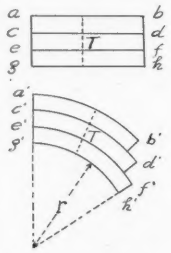

FIG. 79. Deformation of a strata block according to the parallel law.

into the position $a'b'g'h'$. In order for the thickness ac to remain constant and equal to $a'c'$ the lengths ab and $a'b'$ must remain the same. Similarly, ce and $c'e'$ (thickness) and cd and $c'd'$ (length) must remain the same. This means that the folding is accomplished entirely by differential slipping along the bedding planes with no movements in any other direction (except bending under the neutral surface law as mentioned later).

Fig. 80 represents two horizons of a parallel fold separated by constant thickness T. ϕ is the angle of dip being mathemati-

cally measured from 0 to 180 degrees to allow the use of negative and positive values. The relationship between the two hori-

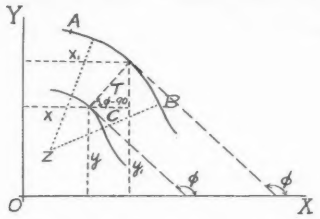

FIG. 80. Geometrical relations of two horizons of a parallel fold.

zons, where (x, y) represents a point on the lower and $(x_1\ y_1)$ the corresponding point on the upper, is

$$\left.\begin{aligned} x_1 &= x + T\ \sin\ \phi \\ y_1 &= y - T\ \cos\ \phi \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Since the dips are the same at both points we have

$$\tan \phi = \frac{dy}{dx} = \frac{dy_1}{dx_1}.$$

Let s_1 be the length of the upper stratum and s that of the lower, measured from the vertical end where the fold starts and the dip is zero. Then from the customary relation for expressing the differential length of arc we have

$$\frac{ds_1}{dx_1} = \sqrt{1 + \left(\frac{dy_1}{dx_1}\right)^2}; \qquad \frac{ds}{dx} = \sqrt{1 + \left(\frac{dy}{dx}\right)^2}$$

and since

$$\frac{dy}{dx} = \frac{dy_1}{dx_1}$$

we get from the above

$$\frac{ds_1}{dx_1} = \frac{ds}{dx}$$

Therefore

$$\begin{aligned} ds_1 &= \frac{ds}{dx} dx_1 = \frac{ds}{dx} (dx + T \cos \phi d\phi) \\ &= ds - T d\phi. \end{aligned}$$

Since T is constant we get on integrating: $s_1 = s - T\phi$. (2)

This shows that between any two points where the dip is zero the lengths of any two strata are the same, such as between the parallel ends bounding the fold, or between anticline and anticline or syncline and syncline. Or what is the same thing the equation indicates that parallel folds are the result of action between vertical parallel ends and can therefore be ascribed to tangential forces.

The last statement needs to be modified by defining more closely what is meant by parallel folds in this paper. To be truly parallel the center of curvature (Z in Fig. 80) must lie outside the fold or no closer than the periphery of the lowest or uppermost bed in the system. If the center of curvature enters the bed a discontinuity occurs, meaning a different system of folds.

From Equation (2) we get the important slip relation $s_1 - s = -T\phi$ which measures the relative slip between the bedding planes, as follows: Point A, for instance, in Fig. 80 measures the end of s_1 and C the end of s. Had there been no slip between the bedding planes A would have coincided with B. That is arc AB represents the amount of tangential slip with reference to C and is measured by the value $T\phi$, where the angle ϕ is expressed in radians.

Fig. 81 represents a parallel fold drawn for simplicity as a

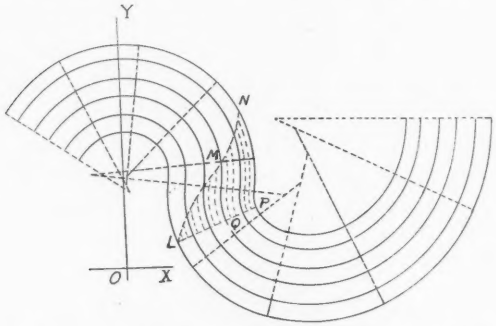

FIG. 81. A parallel fold showing the slip line LMN.

series of circles of different radii. The curved line or slip line *LMN* was a straight vertical line when the strata were horizontal before folding. The shaded portion shows the relative slip with reference to point *L*. Thus *M* has slipped a distance *QM*, and *N* a distance *PN* measured fom a line drawn normal to the dip at *L*. The position of the slip line was calculated from Equation (2). If a thick book is first marked with straight vertical lines and then folded it can be made to approach the conditions of parallel folding.

Features to be noted regarding parallel folds are as follows:

1. The deformation is due primarily to slipping shearing and flow along the bedding planes.

2. The dips are constant along any radial line so long as the center of curvature remains outside the fold under consideration.

3. The dips on an anticline become steeper with vertical depth. On a rectangular similar fold the dips are vertically the same throughout.

4. It seems reasonable to assume that the amount of frictional heat generated by the folding is proportional to the slip, $T\phi$. That is, the greater the dip the greater the amount of heat liberated, increasing to a maximum in the case of overturning. Since there is no slip on the anticlines or synclines where the dip is zero, these portions of the fold are relatively free of such heat, as in the case of similar folds.

5. Under certain conditions the various bent layers of a parallel fold may be under neutral surface conditions, each developing an individual neutral surface, and each bed so formed separated from its neighbor by the usual slipping plane.

NEUTRAL SURFACE FOLDS.

In this type the deformation does not occur primarily by means of flow or slipping as in the previous cases but theoretically at least by the actual elongation or contraction of the components of the rock. Thus in Fig. 82 *abcd* represents a block of flat strata, *dT* an elementary true thickness and *oo'* a surface through the center of gravity. The block is now folded so that *oo'* has

the radius r_0. The rock grains above oo' are then in tension, those below in compression and dT has become apparent thickness dr; the length ab is stretched to $a'b'$ and length cd contracted

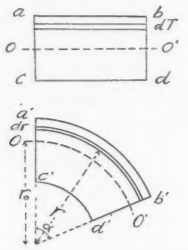

FIG. 82. Deformation of a strata block according to the neutral surface law.

to $c'd'$. The length oo' remains the same and being the locus of no deformation and no stress is here called the neutral surface. This type of folding is therefore essentially one of bending. The mathematical relations for this are that $ab.dT = r a dr$. Since $ab = r_0 a$ we get $r_0 dT = r dr$.

Integrating this we obtain $r^2 = 2\ r_0\ T + C$.

For convenience measuring T from the neutral surface oo', we get that when $r = r_0$, $T = 0$ and $c = r^2_0$ so that the formula becomes

$$r^2 = r_0^2 + 2\ r_0\ T. \qquad (3)$$

The apparent thickness t is expressed by

$$t = r - r_0 = \frac{2r_0T}{r + r_0}.$$

On the usual assumption that the compression and tension stresses are proportional to the contraction and elongation of any arc of radius r, it can be shown that the stresses along any face $c'oa'$ vary at a linear rate. The face oc' is longer than face oa', consequently the total compression on the former exceeds the total tension on the latter. That is, the forces form an unbalanced

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couple which, taken in conjuction with the opposing or balancing forces on an adjacent face, can be resolved into a component acting along the radius r. If we have a series of anticlines and synclines, the stresses, together with the radial components, are a maximum on the anticlines and synclines, and all vanish on the limbs between at the point of inflection, or the point where the curvature disappears. On an anticline the radial component would be directed upward, and on the succeeding syncline downward, so that there would be a tendency for the radial forces to balance along the course of a series of folds.

In the case of an isolated dome formed under the neutral surface law, with flat strata on all sides, the existence of the radial component might be the basis for interpreting the uplift as arising from vertical forces. Such a hypothesis would imply extreme coherence and elasticity of the strata in order for the doming to draw in the ends by stretching without rupture. This condition is conceivable if the bottom of the periphery of the dome floats on a friction reducer such as molten rock associated with a laccolith intrusion. It is not the intention to limit laccolith domes to neutral surface folding or vice versa by this statement. As a general occurrence neutral surface folds are probably the result of tangential movement.

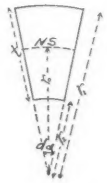

FIG. 83. Geometrical relations of an elementary section in neutral surface folding. *NS* is the neutral surface trace.

At the upper and lower limits of a bed folded according to the neutral surface law we have

$r_1 = \sqrt{r_0^2 + 2r_0T}$ for the boundary of the tension side and
$r_2 = \sqrt{r_0^2 - 2r_0T}$ for the boundary of the compression side.

Hence the apparent thickness t is expressed as $t = r_1 - r_2 = \sqrt{r_0^2 + 2r_0T} - \sqrt{r_0^2 - 2r_0T}$. Expanding the radicals by the binominal theorem and reducing we get

$$t = T\left(2 + \frac{T^2}{r_0^2} + \cdots\right) \tag{4}$$

In general the dips of the beds at r_1, r_0 and r_2 are not the same in neutral surface folding, as can be seen from Fig. 84. To work

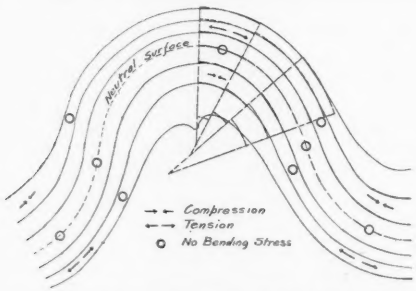

FIG. 84. A neutral surface fold showing the distribution of stresses.

out the relations of dip, strata length and shape of ends for the general neutral surface fold appears to be mathematically difficult, and in this paper we will limit the discussion to the case where the folding has the same features as parallel folding. In order for this relation to exist the term T^2/r_0^2 in Equation (4) must drop out, when we have $t = 2T$ and our fundamental conditions reduce to those of Equation (1) under parallel folds, since the apparent thickness then becomes the true thickness and is a constant. In order for the term T^2/r_0^2 to become negligible and consequently for the conditions of neutral surface folding to approximate those of parallel folding, either of the following must be true:

(*a*) The folding must be very gentle, such that the radius of curvature r_0 is large compared to the thickness T.

(*b*) Or the folded bed must be thin, in which case, if enough thin beds of the neutral surface type can be developed in fairly

close folds. Each bed however would be a unit in itself, and beds so formed could be found in certain of the folded beds in both similar and parallel folds.

It is logical to ask, to what extent can strata be bent without rupture into neutral surface folds? As just mentioned, neutral surface conditions can exist in thin beds even if closely folded, or in thick beds if very gently folded if the physical conditions of the rock are suitable, but the case of a thick bed fairly well bent without rupture of some sort is difficult to visualize. It is posssible that this might be brought about by intermittent and cumulative movements during the interval between which the bending stresses became dissipated through the work of setting the rock, like a piece of steel being annealed or set by heat. After each set, if the forces and bending were repeated in the correct fashion, a fold of considerable magnitude might finally result. Fig. 84 has been drawn on the assumption that a neutral surface fold of this sort could be formed. For this figure the neutral surface was first drawn as a series of circles of varying radii, and then by the above formulæ the position of various beds calculated and plotted. As drawn the figure is an anticline, but by reversing it the conditions become synclinal.

The typical conditions in a neutral surface fold for a given horizon are as follows:

1. Above the neutral surface there would be tension in the anticlines and compression in the synclines, with a place of no stress at the point of inflection somewhere on the limb between.

2. Below the neutral surface there would be compression in the anticlines and tension in the synclines, with likewise a place of no stress on the intervening limb.

3. Above the neutral surface the strata would tend to thin on the anticlines, and thicken in the synclines. Below the surface, the reverse conditions would obtain. On the limbs at the points of inflection the apparent thickness would approach the original true thickness.

The variation in stress from tension to compression along the

same horizon in neutral surface folding may influence the storage and migration of liquid in the bed. The portions in tension may be physically more capable of holding liquid in storage than those parts in compression, from which in fact there would be a tendency to loss of liquid by squeezing brought about by the compressive stresses.

Again if we reason that where the stresses are most active the greatest frictional heat is formed, we would find for neutral surface folding opposite heat conditions to those pertaining to similar and parallel folds, for with neutral surface folds the heat effects would be a maximum on the anticlines and synclines and vanish on the limbs, while with the other two types of folds the distribution is the reverse. As pointed out previously, a parallel fold and to a less extent a similar fold may contain certain beds folded with neutral surfaces, and in cases where such conditions exist there would be a tendency for the heat to be more uniformly distributed than where either type occurred alone.

COMBINATION OF THE TYPE FOLDS IN THE SAME SECTION.

Under certain conditions there does not appear to be anything in the preceding which militates against the occurrence of all three types conjointly in the same section. It has been shown that in a similar fold the lengths of folded beds between two ordinates are equal, and in a parallel fold that the lengths are equal between those points where the dip is zero. It was shown that a neutral surface fold had the characteristics of a parallel fold in mathematical features when either the folding was very gentle or each individual bed very thin.

In Fig. 85 is shown a combination of similar and parallel folds resulting from tangential movement between parallel vertical ends. Certain of the beds in each system may be under suitable conditions to have developed neutral surfaces as bed *DBF*. MNO represents the top of a parallel fold; it also represents the base of a similar fold. Hence the lengths of strata in both types are the same, and this is true for the entire section. In this way we can draw an alternating series of parallel and similar folds and all

the beds are the same length. There is therefore nothing contrary mathematically to drawing a section in this manner. If then it be admitted that all three types can occur simultaneously,

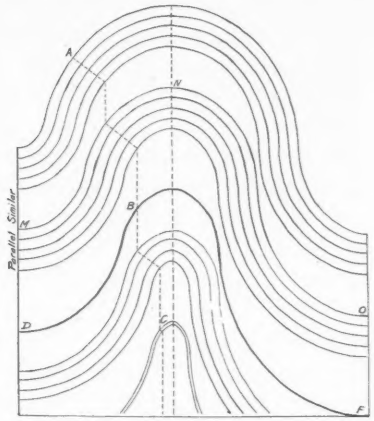

FIG. 85. Hypothetical section showing parallel and similar types in the same fold. Bed *DBF* under neutral surface conditions.

the reason must be sought in the physical differences of the beds making up the section. That is each type of fold would be characterized by a certain kind of rock, such as the following:

1. The beds making up the similar folds should be plastic and yielding, as clays and shales.

2. The essential requirements for parallel folding are that the strata have well developed bedding planes capable of differential movement and that the layers be not too thick. Certain of the folded layers may develop neutral surfaces, or the deposit may be so thinly bedded or the slipping planes so closely spaced that the neutral surface effects are negligible. Alternating layers of limestone, sandstone and hard shale would tend to form folds of parallel type.

3. In order to develop a neutral surface the bed should be tough, homogeneous and elastic. Such conditions might be

found in limestones, igneous rocks and some sandstones, oil shales and the like.

Fig. 85 then may represent a hypothetical way of drawing a section when the folding is due to tangential movement, the beds not overturned, and bedded deposits alternate with soft strata. The line *ABC* represents a locus of constant dip, as everywhere along this line the dips are the same. On an anticline such as is shown the line migrates from the flanks inward towards the crest of the fold. With increase in depth the thickness of strata that can be drawn in true parallel folds becomes less and less, so that in the region where the line of constant dip intersects the crest, as near *C*, the conditions for parallel folding disappear, and if the section is carried below this, it must be done with similar folds. As the physical condition may be suitable for parallel folds below this depth, we would then have a break or discontinuity appearing meaning the introduction of another system with different parallel ends.

Except for the visual evidence of small exposures there is not much data at hand to show whether the above hypothesis is approached on any scale in nature. In Wyoming and Montana there is evidence that the folding in the thick shales on some of the asymmetrical anticlines is of the similar type, but whether the harder bedded deposits above and below are in parallel folds is not known, to the writer's knowledge. Hewett[2] in describing the Cottonwood anticline of the Big Horn Basin mentions that the Cody shale is only 1900 feet thick on the steep side of the fold where the dip is around 60 degrees, the thickness measured perpendicular to the dip. On the gentle flank of the anticline where the dip is 10 degrees the thickness is 2,950 feet, and on account of this variation in a few miles there is evidence of similar folding in the shales. The type of folding in the lower harder beds might be determined from well logs, as the anticline is an oil producer.

[2] D. F. Hewett and C. T. Lupton, "Anticlines in the Southern Part of the Big Horn Basin, Wyo." Bull. 656 U. S. Geol. Survey, p. 148.

On the producing asymmetrical Cat Creek anticline in Montana it is reported that the crest of the anticline is offset toward the steeper side with depth. The crest of the fold is in the Colorado shale, around 2,000 feet in thickness, below which occurs the harder Kootenai formation whose top shows the offset mentioned. It may be that the offsetting is due to oblique similar folding in the Colorado.

In the examination of certain coal workings sections in the North Staffordshire coal field of England, the writer noted in one case the narrowing together of two coal seams in rising from a flat dip onto the flank of an anticline. The convergence was quite pronounced, the dip running up to 60 degrees, and suggested similar folding in this horizon, the section being based on surveys in the coal seams. There was evidence that a sandy member above was a parallel fold, although the evidence was not as satisfactory as with the coal seams.

In a paper by Conkling [3] it was shown that at the Cushing field, Oklahoma and some other fields in the Mid-Continent, there is a thinning of strata on the crests of anticlines. Thus at Cushing the shale interval between the Bartlesville and Tucker sands is 200 ft. in the syncline and 135 ft. on the neighboring anticline. If a part of this thinning is due to folding, it may be caused by neutral surface conditions, as was pointed out by Ohern in the discussion. As the dips are gentle and the same conditions seem to occur in other districts, the evidence for neutral surface folding seems worthy of consideration.

Los Angeles, Cal.

[3] Conkling, R. A., "Influence of Movements in Shales on the Limits of Oil Production," *Trans. Amer. Inst. Min. Engrs.*, vol. LVI., p. 876.

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THE CHEMICAL COMPOSITION OF THE NORITE-MICROPEGMATITE, SUDBURY, ONTARIO, CANADA.

CYRIL W. KNIGHT.

In order to obtain a more complete knowledge of the chemical composition of the norite-micropegmatite at Sudbury, Ontario, Canada, the writer took a systematic suite of seventeen rock samples, beginning at the outer edge and continuing at more or less regular intervals across the eruptive to the inner edge. The samples were obtained from that part of the Sudbury nickel area known as the Eastern Nickel Range. The norite-micropegmatite along the Eastern Range is comparatively narrow. The samples were obtained in MacLennan township on lots 11 and 12, in the third concession, the width of the eruptive there being approximately 8,300 feet along the section line.

Selection of Samples.—A line was surveyed with prismatic compass and steel tape across the eruptive from the outer to the inner edge, and stakes were placed every hundred feet.

Samples were taken along this section line at as regular intervals as possible. It was not found practicable, however, to obtain the samples at absolutely regular intervals on account of the presence of glacial drift here and there. The samples were taken, nevertheless, for the most part, every three or four hundred feet. The first sample was obtained 100 feet southwest of the outer edge of the norite; the next sample was taken 300 feet southwest of the outer edge; the next 1,200 feet; the next 1,500 feet, and so on, as shown in the table below, until the inner edge was reached. The inner edge is drift covered so that the exact location of the contact is not known. The nearest sample to the inner edge was obtained 1,200 feet, approximately, from the edge. It is probable that it would not be safe, for purposes of chemical analysis, to take a sample any nearer the edge than about 1,200 feet owing to the fact that the micropegmatite has absorbed part of the sediments with which it is in contact on the inner edge. According to A. P. Coleman this impregnation of the sediments

TABLE SHOWING CHEMICAL COMPOSITION OF THE NORITE-MICROPEGMATITE, SUDBURY, ONTARIO, CANADA.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.	No. 11.	No. 12.	No. 13.	No. 14.	No. 15.	No. 16.	No. 17.
SiO_2.....	56.21	57.10	57.74	58.19	53.14	52.86	66.05	69.08	67.80	69.10	68.76	69.84	66.58	66.50	67.40	64.04	68.50
Al_2O_3.....	22.85	15.93	19.93	18.67	23.17	18.34	11.46	11.55	14.32	13.95	14.55	11.90	11.79	15.26	15.01	14.89	12.57
Fe_2O_3.....	1.25	4.40	1.51	2.28	0.71	4.67	5.95	5.55	4.36	2.93	2.40	4.00	5.08	1.61	1.94	4.14	2.37
FeO.....	4.80	4.87	5.36	5.72	7.02	7.99	3.79	2.98	3.22	3.43	4.04	3.74	4.51	4.28	4.62	5.71	5.13
CaO.....	4.22	5.35	5.67	6.62	5.20	5.57	2.25	2.10	1.44	1.08	1.65	1.64	1.95	2.26	2.07	2.27	2.07
MgO.....	1.24	4.74	1.95	2.32	2.68	3.45	0.80	0.80	1.16	1.15	0.67	0.72	1.44	1.88	1.13	0.97	1.09
Na_2O.....	3.69	3.24	3.28	3.08	4.20	4.52	4.44	3.66	3.05	3.64	3.21	3.44	3.33	3.40	2.94	3.73	3.27
K_2O.....	3.45	1.92	1.67	1.48	2.14	0.79	3.60	2.66	3.14	3.58	3.58	3.27	3.66	3.16	3.37	2.43	3.30
H_2O.....	2.56	2.55	2.67	1.88	1.73	1.79	1.84	1.30	1.46	1.10	1.22	1.38	1.62	1.66	1.65	1.93	1.64
CO_2.....	.....	0.20	0.31	0.16	0.18	0.18	.....	0.24	0.24	0.21	trace	0.26	0.25	0.18	0.17	trace	0.27
	100.27	100.30	100.09	100.40	100.17	100.16	100.18	99.92	100.19	100.17	100.08	100.19	100.21	100.19	100.30	100.11	100.21

These samples are, beginning with No. 1, 100, 300, 1200, 1500, 1800, 2100, 2600, 2900, 3500, 4000, 4600, 4900, 5800, 6200, 6500, 6800, and 7100 feet, respectively, southwest of the outer edge of the norite-micropegmatite.

Analyses previously published will be found in the Report of the Royal Ontario Nickel Commission, pp. 117–119.

includes a belt hundreds of yards wide, making it difficult to locate the contact between the micropegmatite and sediments.

Each sample consisted of a dozen chips about an inch square. The chips were obtained within an area included in a circle ten or fifteen feet in diameter. The samples, therefore, constituted a reasonable approximate to the average composition at each place sampled.

The analyses were made in the Provincial Assay Office of Ontario, by W. K. McNeill, Provincial Assayer, and T. E. Rothwell, Chemist.

Results Obtained.—The analyses confirm, in a general way, what has long been shown by A. P. Coleman, T. L. Walker and A. E. Barlow, namely, that the norite-micropegmatite is basic at the outer part, and becomes more and more acidic as the inner part of the eruptive is approached.[1]

But the analyses show, further, that the most basic part of the eruptive is not along the outside edge, but from 1,500 to 2,100 feet from the outside edge. The analyses also show that the most acid part is not along the inner edge, but from 3,400 to 4,300 feet from the inner edge, indeed, nearer the center than the edge. In other words, the transition from basic to acid facies is not a gradual one.

Tests for nickel and copper were made and neither of these metals was detected.

If some half dozen or more similar sections were made across the eruptive at various places, further light would no doubt be thrown on this, one of the most interesting and widely discussed igneous intrusions in the world.

The writer offers no apology for the briefness of this article, as the point of chief interest is the analyses themselves.

ONTARIO DEPT. OF MINES,
TORONTO, ONTARIO, CANADA.

[1] T. L. Walker, "Geological and Petrographical Studies of the Sudbury Nickel District," *Quart. Jour. Geol. Soc. London*, 1897, vol. 53, pp. 40–65. A. E. Barlow, "Nickel and Copper Deposits of Sudbury, Canada," *Geol. Sur. Can.*, 1904, vol. 14, Part *H*. (Reprinted in 1907.) A. P. Coleman, "The Sudbury Nickel Field," Rep. Ont. Bur. Mines, vol. XIV., 1905, Pt. III., pp. 1–188. "The Nickel Industry," Dept. of Mines, Canada, Bull. No. 170, 198 pp., 1913.

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EDITORIAL

THE EDUCATION OF A GEOLOGIST.

In the infancy of geology, the question of training for a geological career was easily settled. If any was to be obtained at all, it was identical with that for other sciences. One normally went to a medical school where one learned all that was known not only of scientific method but of scientific fact. But the training was of secondary importance, provided one were naturally endowed with the spirit of enquiry. Thus, while Hutton, the father of physical geology, entered the field of geology from medicine and agriculture, his expositor, Playfair, was a professor of mathematics and physics, and William Smith, the father of stratigraphical and historical geology, was a self-educated civil engineer.

With the pioneer work accomplished and the basal sciences more highly developed, preliminary training assumed greater importance but was met more or less satisfactorily by the progressive development of the scientific departments of the universities. For a long period the problem was to decide on the knowledge and training that might prove useful to a geologist. Later, with the accelerated growth of the subject, and correlated sciences, the question became, what is indispensable? Now, even that has become impossibly large, and a college course represents merely an opinion on how the limited time that a student can devote to preparation for a career in geology may be most usefully employed.

Naturally, there are widely divergent views, and it is a good thing in may ways that the workers entering so broad and varied a field should possess varied equipments.

Yet a careful survey and general discussion by practicing geologists would be of great service, for though it is scarcely likely

that any concensus of opinion would be reached, some broad guiding principles would undoubtedly emerge that would be helpful to their academic brethren.

In the present curricula there must be "hangovers" from an earlier period that might well be eliminated; subjects stressed that might better be left to be mastered as required or when opportunity offers, during professional life; and material that furnishes a necessary background, or an invaluable tool, and that must be acquired at college or not at all, crowded out completely.

In several of the professions, where their problem is not so complex, the practicians have greatly assisted the educationalists in improving the professional training. By considering and discussing the education of a geologist, economic geologists may be able to render a distinct service to the rising generation, to the science, and the profession.

Personally, I am inclined to favor, as the general rule, a good engineering training in the undergraduate course with a postgraduate course in geology, particularly when the engineering is a broad general course that stresses English and some cultural subjects and includes all the basal sciences. Theoretically, it should be a satisfactory, if not the best, foundation for geology. To mention only some of its advantages: It gives the student the mathematics and the various sciences, whose application to the study of the earth constitutes the science of geology; he learns to apply this knowledge and to do things; he acquires the right attitude and habit of mind; he learns to treat problems concretely and in quantitative terms; he learns draughting, surveying, and mapping; he is at home in the field; he becomes familiar with the engineer's problems, and thus as a geologist knows where and how to help him and how to put his results in forms that the engineer can appreciate and use.

Practical results, so far as my experience goes, seem to confirm the above theoretical conclusions. No one of my former students with arts training has become a first-class practicing geologist—a large proportion of those with an engineering training have. True, those who have come to me with an arts train-

ing have been fewer in number, for my advice has always been to prepare for geology by taking an engineering course, preferably a special course I have called geological engineering. But some of these arts men have been first-class students and there have been a sufficient number of them to have furnished some successful practitioners, if something had not been wrong in their training.

Even the palæontologist considers his engineering training the most valuable part of his college work, and would now be willing to sacrifice any other part of his course for it. (As I was responsible for a small part only of his geological training, I overlook the implied compliment.)

I mention my experience and viewpoint to introduce the subject to those who are in a position to give the universities timely and valuable advice.

R. W. Brock.

DISCUSSION AND INFORMAL COMMUNICATIONS

CAPILLARY RELATIONSHIPS OF OIL AND WATER.

Sir: This experiment is an important and definite accomplishment. The strength of the experiment lies in its strict simplicity, Cook having eliminated the effects of gas surfaces, thereby avoiding several complications. He deals only with two or three kinds of surfaces, namely (1) solid-water, (2) water-oil, and possibly (3) solid-oil. The third is doubtful because we do not know whether under the conditions of the experiment there was actual contact at any time of oil against glass or whether the oil was separated even initially from the solid by a molecular film of water. In natural migration through rock pores there probably always is much adsorbed water on the pore walls, if not a complete molecular film of water.

One is obliged to accept Cook's evidence that the transfer of oil and water through a capillary tube is accomplished by the water moving one way along the walls while the oil moves the other way through the center. This observation is personally welcome to the writer since it facilitates his theory of the capillary concentration of oil in the larger pores of rock.[1]

Would a similar but smaller transfer occur if the two bulbs terminating the capillary tube contained only oil and water respectively without sand? Would it occur if the sand in each bulb were of the same coarseness; or if water first occupied the fine sand, and oil the coarse sand, in reverse of the conditions adopted? In these cases, how much, if any, water would pass into the coarser sand? About how thick was the thin sheet of water moving through the capillary? To what extent was the

[1] C. W. Washburne, *Trans. A.I.M.E.*, vol. 50, p. 829, 1914.

oil driven out of the fine sand? The author may be able to answer some of these queries now without further work. The experiment needs further description also as to kind of oil and water used, or the size of sand grains. He writes only enough to show us he has something good. We want more.

The author brings out clearly the preponderant force of the attraction of the pore walls on the molecules of water, which he calls "adhesion." This force has been estimated by Carl Barus to amount to thousands of atmospheres at normal temperatures. It is the cause of the phenomena described. On account of it water spreads as far as possible over all pore walls, slipping between the oil and the walls. It is evident that in pores sufficiently minute two water films of molecular thickness would fill the pores completely, crowding out all the oil which could escape into larger pores. It is probable, however, that water films are effective in this process to a thickness of many times the sphere of molecular influence, because the inter-attraction ("cohesion") of water molecules is much greater than that of oil. This should tend to thicken the water films at the expense of thicker bodies of water in the larger pores.

This experiment clearly presents an essential factor in capillary migration, but does not mean that the attraction of the wall rock on water molecules is the only important force. It is true that is the reason why water "wets" the capillary walls, and the main cause of movement. But the effective pressures generated within the capillaries must be limited by the strength of the liquid-gas surfaces, which are always present. The author is fortunate in being able to clarify the mechanics of capillary by not having liquid-gas surfaces in his apparatus.

The writer now sees that in his own paper on capillary concentration he over-emphasized the importance of liquid-gas surfaces. Yet since gas always is present, its effect in promoting and in retarding capillary concentration must not be forgotten. The writer believes that the conclusions reached in his paper on capillary concentration remain true, but he welcomes this new

evidence on the essential importance of the attraction of pore-walls on water molecules.

Cook's formulas may be correct, but they are not understood for lack of fuller explanation. It is not clear what surfaces are involved in the statements referring to surface tensions. For instance, the writer does not understand what is meant in the formula on p. 170 by the statement "ds = differential surface tension of water." From the promise in this short paper the author owes us a fuller paper on the same subject.

His patience in conducting single experiments for three years is admirable, as are also his remarks concerning the importance of the time element in geological problems. Our literature is full of hasty conclusions from laboratory experiments which neglect the the effect of time. Forces like gravity, always pulling downward, and capillarity always tending to concentrate oil and gas in the larger spaces, can accomplish results in geological time that may seem impossible from a short laboratory experiment.

CHESTER W. WASHBURNE.

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PETROLEUM BEARING CONCRETIONS.

Sir: Ordinary concretions are so common a phenomenon to geologists that they attract little attention, but certain limestone concretions in Arkansas have the unique distinction of containing petroleum and are therefore of unusual interest.

These concretions are in a steep bluff parallel with a small creek in Sec. 11–15N–21W, township of Jasper, Newton County, Arkansas, and to my knowledge are not known elsewhere. They are imbedded in a rock which at first glance appears to be a black slate but in reality is a calcareous shale. This formation can be correlated with the Fayetteville described in a quadrangle a few miles to the west.[1] The shale is noted for the strong petrolifer-

[1] U. S. Geol. Surv., Fayetteville Folio, No. 119, 1905.

ous odor that is emitted when a sample of it is freshly fractured. This is also characteristic of a dark limestone of the same formation. Although calcareous concretions have been noted as occurring in the Fayetteville formation elsewhere,[2] no mention of their containing petroleum has ever been made.

The concretions are all well rounded, of a grayish-black color, and vary in size from that of an apple to a man's head. They have a decidedly massive and fine-grained structure; the concentric rings so frequently to be seen in most concretions are entirely lacking. When broken open, the concretions show two internal cavities in the form of a cross which implies contraction of the interior, after the outside had formed, along two planes normal to one another. These hollows are lined with well developed calcite crystals that in exceptional cases completely fill them. The bedding planes of the enclosing strata lap around the concretions which in turn are loosely attached to the rock by a small protuberance or stem that extends out along the bedding planes. This stem must be broken to obtain a concretion and because of this queer attachment the concretions have been called "oil cocoanuts." The concretions are not localized by faults or fissures and their position with respect to the bedding planes suggests that they were formed at the same time as the enclosing rock. Although the enclosing rock is shale the concretions are lime—a condition to be expected according to Geikie's explanation[3] for the formation of concretions. "In most cases they (concretions) owe their origin to the gradual aggregation of mineral matter originally diffused through the mass of the rock in which they occur. Occasionally, however, the mineral matter has been introduced from the outside by percolating waters. . . . Frequently they form round a nucleus, which may consist of mineral matter, but is more commonly organic." About five out of eight concretions contain oil, but these can be determined only by cracking open several of them.

The amount of oil contained in them is easily overestimated;

[2] *Idem*, p. 4.

[3] Geikie, James, "Structural and Field Geology," p. 120.

some appear wet with oil when opened but not a drop will flow, whereas others contain as much as twenty cubic centimeters. In one case evaporation had produced a dark green vaseline, but this is uncommon. The oil is dark greenish-yellow in reflected light and light brown in transmitted. It is a paraffin base oil and will burn with a yellow flame upon continued application of heat. I was unable to take any gravity measurements but presume it is a "light oil" since it evaporates readily when exposed to the air and smells strongly of gasoline.

If oil and water were present in sediments, the oil, according to Washburne,[4] would be forced into the largest openings. With the Fayetteville concretions the pore space of the walls is of capillary size whereas the centers are hollow, therefore the oil should seek the center. The presence of calcite crystals coating the central openings of the concretions shows that water has percolated into them and deposited its load of calcium carbonate. Twenhofel in his study of the Baltic Sea oozes[5] found them to contain as high as five per cent. of half decayed organic matter which will in time form petroleum, provided the oozes are consolidated and igneous activity does not burn the material or denudation allow it to evaporate. If it is assumed that the Fayetteville muds and oozes during deposition in Mississippian time were similar to the Baltic oozes of today, then as the concretions formed, half decayed organic matter may have served as a nucleus or may have been present in the concretionary body and was later forced to the center. It seems more probable that to start with the oil was diffused through the shales.

In various localities of Oklahoma a productive sand, the Burgess, is found which is just below a black shale that occupies the position of the Fayetteville and is probably the same formation. This sand comes in and plays out similarly to the Batesville, a local sand near Jasper, and undoubtedly the two are equivalent. In both cases it is not begging the question to assume the Fayette-

[4] Washburne, C. W., *T.A.I.M.E.*, vol. 50, pp. 829–842, 1914.

[5] Twenhofel, W. H., "Notes on Black Shale in the Making," *Am. Jour. Sci.*, 4th Series, vol. 40, pp. 272–280, 1915.

ville to be the source of the petroleum. The lack of occurrence of oil bearing concretions elsewhere points to this locality as an exception, but possibly the finding of such phenomena may have some bearing on the location of productive areas in the future provided the structural and stratigraphic conditions are favorable.

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REVIEWS

Anleitung zur mikroscopischen Bestimmung und Untersuchtung von Erzen und Aufbereitungsprodukten besonders im auffallenden Licht. By HANS SCHNEIDERHÖHN. Gesellschaft Deutscher Metallhütten und Bergleute, Berlin, 1922. 8vo, pp. xv + 292, with 159 figs. and 15 tables.

The study of ores in reflected light has been hampered by the lack of any thorough exposition of the mineralogy of the opaque minerals as revealed by the microscope. A long stride towards overcoming this deficiency has been made by Dr. Hans Schneiderhöhn, professor of mineralogy and petrography at the University of Giessen. His book, "Manual for the Microscopic Determination and Investigation of Ores and Ore-dressing Products, especially in Reflected Light," has been published by the German Metallurgical and Mining Society at the instigation of the committee on ore dressing. The book will be useful both to the mill man and to the geologist. The book is divided into two parts—the first "general" part contains a description of instruments, methods, and generalizations on the mineralogy of the opaque minerals as revealed by polished sections; the second "special" part contains full descriptions of the most important ore minerals. A great store of valuable information is presented, much of it new. The most important contributions are the use of polarized light as a means of investigating opaque minerals, a full statement of the etching properties of many minerals, using some new and valuable methods, and a precise determination of color of polished sections. Much of the work was done with limited facilities and the author admits the incompleteness of his work. For that reason he does not give any determination tables. Nevertheless, the book is one that should be in the hands of every geologist engaged in the microscopic investigation of ores.

At the outset the author adopted the term "chalcography" (χαλκός = ore), proposed by R. Brauns, for the study of polished sections of the metallic minerals in reflected light. The choice seems a happy one and the word better than any previously proposed. The analogy to the word "petrography" is obvious and proper.

Instruments are described in the first part of the book. A new binocular ore-dressing microscope made by Leitz from specifications of the author is worthy of note. It is designed to give a large field of view

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and to preserve this only one set of objectives and three sets of oculars are used. Grid micrometers for insertion in one occular tube give 5 standard screen sizes. A dish-shaped stage permits the fragments to be examined immersed in water. Petrographic and chalcographic microscopes are also described.

To use polarized light a polarizer is attached, either to a condenser stand placed between the light and the microscope, or in front of the collimating lens of the vertical illuminator. This last method seems to the reviewer to be the best. Incidentally it requires a smaller prism. The analyzer is either in the tube or in the form of a cap nicol. The reviewer submits that it should be a cap nicol with as accurate graduations as possible and that either the cap or the tube should permit the insertion of a Wright biquartz-wedge-plate below the analyzer. It may be noted that Leitz furnishes a polarizer attachable to the horizontal tube of the vertical illuminator. The author disapproves the use of the inverted type of metallographic microscope and the present tendency in this country seems to be away from this type. The use of polarized light should complete the change. The reviewer attempted to adapt an inverted microscope for polarized light but found that the extra reflectors in this type of microscope cause serious disturbing effects.

The chapter dealing with the examination of ore dressing products with the binocular ore-dressing microscope and a subsequent chapter on the examination of polished sections of the same material mounted in sealing wax should prove stimulating to the economic geologist. Some economic geologists engaged in ore-dressing problems have applied these methods, but surely much greater attention might be given to the mineralogical flow-sheet, and the result of a process, at least in the experimental stages, gaged more by the mineralogical concentration.

Petrographic methods, especially determination by the immersion of fragments, are discussed. Several of the immersion liquids recommended by Schneiderhöhn, as obtained commercially, are of uncertain indices, *e.g.*, bromoform, and the set would have to be standardized by the user or dealer. A few simple miscible liquids could be chosen and a set made of any desired intervals. If the user was not supplied with a refractometer the few liquids of known index might be furnished and a set of any desired even intervals might be made by mixing measured volumes of the various liquids by running them out of a burette. A simple set of miscible liquids, as selected by H. E. Merwin,[1] is as follows: isoamyl isovalerate, $n = 1.41 \pm$, albolene, $n = 1.47 \pm$, alpha monobromnaphthalene, $n = 1.658$, methylene iodide, 1.741. Dr. Merwin reports that these liquids may be mixed by volume to give an intermediate prod-

[1] Personal communication, May 11, 1923.

uct whose index will be accurate within .001, provided the index of the original liquids is precisely known.

The chapter on the preparation of polished sections is of interest as the author has worked out his own methods. Schneiderhöhn favors a horizontal lap in that more of the cutting medium is retained and for the same reason favors a low speed, little over 500 R. P. M., were possible. The cutting disks and laps used are as follows: coarse carborundum disk, fine carborundum disk, steel lap to be used with very fine emery, ground glass lap to be used with very fine emery, steel lap to be covered with linen cloth and used with the very finest emery, and, for polishing, a steel lap with cloth covering to be used with polishing media. For aggregates of hard minerals the coarse emery disk is used wet and at a rather high speed, then the fine emery disk on which the specimen is held lightly. Then fine grinding is done on the lap covered with linen by means of very fine emery prepared by floating 20–60 minutes the finest commercial product. This fine grinding is continued until no coarse pits are visible with a hand lens. Many minerals will show a dull polish at this stage. Care must be taken to prevent the cloth getting too dry, for although a high polish may be attained, the surface of the mineral is put under such strain as to show misleading effects later. To produce the highest polish 60 minute emery is applied to the same cloth and then another cloth with 200 minute emery is used. For very soft minerals or aggregates of soft and hard minerals Schneiderhöhn uses after the carborundum disks a steel lap with 60 minute emery and then a ground glass lap with 60 minute emery, followed, after washing the lap, with 200 minute emery. For the final polish of all minerals a soft cloth and the softest medium possible are used. Rouge, or better, alumina formed by heating ammonia alum, is used for the hardest minerals only. For the moderately hard and for soft minerals magnesia is used. For the soft minerals one thickness of linen or flannel is used, but for the hard minerals two or more thicknesses of flannel or of dense thick broadcloth are used. Magnesia is to be used with care for the wet powder takes on CO_2 from the air and forms a magnesium carbonate with hardness 4. Polishing is done at about 500 R.P.M. The polishing stage should be completed in 2 or 3 minutes, long polishing tending to produce marked physical changes at the surface of soft minerals. The native minerals are prepared by successively finer grades of emery paper given a final polish on a felt-covered lap with Cr_2O_3 or Al_2O_3.

A chapter of 73 pages is devoted to the investigation of polished sections in non-polarized reflected light. The chapter opens with a section contributed by von M. Berek on the "Basis for the Determination of Minerals on the Ground of the Optical Phenomena which they Present in Vertical Incident Light, both Natural and Polarized." The treatment

is simple and the results stated without recourse to mathematical presentation. It is to be regretted that the statement is not more full, particularly that dealing with the anisotropic absorbing minerals. This section will not bear condensation here. It is mainly a clear, brief statement of non-polarized results which can be found in various texts on physical optics.[2]

A section of 38 pages is devoted to "observations on specimens only polished and not otherwise treated." Among the many headings are: Form of mineral grains, observation of cleavage, and observations on hardness. Relief receives particular attention, and in dealing with the accurate determination of color the author has made a great contribution. The mineral grains are compared by a camera lucida attachment, half the field of the occular being cut out by a black paper so that the mineral grain and a card showing the color are brought into contiguous parts of the field. Precautions is taken so that the color card is illuminated by light identical to that used for the microscope. The author uses the color plates produced after the system of von M. Ostwald. A condensed quoted description is given of the method of classification. The "Farbenatlas" of Ostwald contains about 2,500 colors arranged on loose cards. The "Farbtonleitern" used by the author contains about 700 colors. Dr. Irwin G. Priest tells the reviewer that the Farbenatlas is no longer in print but that he has been informed that a new edition ("Normenatlas") is forthcoming (Verlag Unesma, Leipzig, Kantstr. 7), probably ready in part early in the summer. The Ostwald collection of plates, although based on less sound theoretical basis than the Munsell, is at present the best standard for the purpose.

Schneiderhöhn has done valuable service for chalcographers in his color work; the color of 52 minerals has been determined, of which, however, 19 are nonmetallic. Much more work remains to be done. For example, between what limits may the color of one mineral vary. Schneiderhöhn shows, for example, that with stibnite and galena, there may be an appreciable variation.

The author also states that one may determine whether the index of most minerals is above or below 3. If below 3 the mineral will be appreciably darker when seen with an oil immersion objective. Using this same principle, that as the index of the immersion medium approaches that of the mineral the amount of reflected light decreases, the author points out that in the partly transparent minerals the colors of inner reflection, which may serve as a diagnostic aid, may be seen better with an oil immersion system than with a dry system. A section, illustrated by 14 excellent plates, is given to characteristic inclusions of minerals. The author holds that many inclusions of the type chalcopyrite in sphalerite

[2] Wright, F. E., "Polarized Light in the Study of Ores and Metals," *Proc. Am. Philos. Soc.*, vol. 58, pp. 481–447, 1919, and references therein, p. 402.

are unmixing of solid solutions. Two especially instructive photographs are, stannite in sphalerite, and the reverse, specks of sphalerite (and some chalcopyrite) in stannite. Figures 50 and 51, showing respectively a lattice intergrowth of chalcopyrite in bornite and irregular areas of pentlandite in pyrrhotite, do not seem convincing.

A section of 13 pages is devoted to the methods of etching polished sections. Two objects are distinguished at the outset: first, the determination of unknown minerals, and second, the demonstration of structure. For routine determinative work the following reagents are used: HNO_3, HCl, KCN, KOH, and acidified $KMnO_4$. The acidified $KMnO_4$ has been used by the author with great effect and may well be included in a limited set of determinative reagents. For the development of structure additional reagents are used. The most important new reagents are: acid $KMnO_4$ in the proportion 1 cc. of concentrated $KMnO_4$, 1 cc. of H_2O, and 1 drop of concentrated H_2SO_4, the acid being added just before use, and the stock solution being kept for only 1 or 2 days; and alkaline $KMnO_4$, 1 part KOH and 1 part $KMnO_4$. A table is given showing for 36 minerals the best method of developing structure in an aggregate of the single minerals. It is pointed out that a knowledge of the relative rate of etching in different crystallographic directions may prove useful in determining the orientation of a grain and which may be in turn useful in determining the orientation of structures, *e.g.*, twinning, developed by etching. A table is given showing the best reagent and method for developing cleavage in 9 minerals. It is of interest to note the development of cleavage in arsenopyrite by alkaline $KMnO_4$.

Much attention has been given to the demonstration of twinning lamellæ. The author distinguishes two types of lamellæ—long, straight lamellæ bounded by parallel surfaces, termed "growth twins," and short, spindle-shaped lamellæ, generally corrugated and bounded by curved surfaces, designated as "alteration twins," the first, primary structures, the second, brought about by alteration of a form stable at high temperature to a form stable at low temperature. A tabular summary is given of the methods of developing twinning in 14 minerals. Some of the reagents *e.g.*, ammoniacal copper ammonia chloride (Heyn's reagent), for native copper, are new to chalcographers.

The chapter on "the investigation of polished sections with polarized incident light" contains only 5 pages of text and seems to the reviewer inadequate. In the mineralogic descriptions much and valuable use of polarized light has been made and Schneiderhöhn must have much additional valuable information which might have been included.

Under sources of error the writer points out that although imperfections in polishing may cause disturbing effects yet their magnitude has been overestimated. They have little appreciable effect on qualitative

observations. A much more important source of error is due to the anisotropism of the glass of objectives. The rotation of the plane of polarization is an extremely delicate test and it will be found that, as the reviewer has verified, the most expensive objectives may cause a brightness under crossed nicols when they are rotated. Positions must be marked in which they cause no brightening. Under crossed nicols the grain structure of anisotropic metallic minerals is readily apparent, differently oriented grains extinguishing in different positions. Twinning structure is also brought out. In a replaced mineral the like optical orientation of disconnected grains may be shown.

Schneiderhöhn explains some of the apparently anomalous colored effects produced under crossed nicols. He points out that colors in the bright position may be due to dispersion of the indices of refraction or indices of absorption.

Schneiderhöhn concludes that no quantitative observations can be made with polarized light. The reviewer thinks that this may be possible and contributes a note as to results that he obtained to the section for "Discussion" of this journal.[3] Schneiderhöhn does not use the Wright bi-quartz-wedge-plate for the detection of anisotropism. This is a very useful accessory and may be easily used with great effect.

The second part of the book, consisting of 130 pages, of which about 28 pages are illustrations, takes up "The Characteristics of the Important Ore and Gangue Minerals as Revealed by Microscopic Investigation of Polished Sections in Reflected Light." Under this heading are described 25 sulphides, simple and mixed, 8 hypogene oxides, 8 oxidized supergene minerals, 3 native elements, and notes are given on some of the gangue minerals.

A large amount of valuable material is collected here. Most of it is original. The following subjects are treated for each mineral: Capacity to receive polish and condition of polished surface, hardness, cleavage, power of reflection and color of polished section in air, color after system of W. Ostwald, behavior in polarized light, etching behavior, inner condition of the individuals, deformation, joining together of the aggregate, recognition and differentiation of the mineral; a list is given of the localities from which mineral has been studied. Under "Capacity to Receive Polish and Condition of Polished Surface" is given the best method of polishing the mineral. Under "Hardness" is given the Moh's scale number and notes as to relative hardness compared with commonly associated minerals. Under "Cleavage" the orientation is given and notes as to its occurrence and appearance in polished section. Under "Power of reflection and color of the polished section in air" is given a verbal description of the color, particularly as compared with other

[3] To be published later.

minerals. "Ostwald color" is given under a separate heading. Both the index number of the color and per cent. each of white, black, and spectral hue are given. The sections on "The Behavior in Polarized Light," describe well the observed phenomena. The intensity of anisotropic effects is described under this heading and the more unusual phenomena, such as colors at the position of extinction, are mentioned.

By the use of polarized light Schneiderhöhn has recognized two allotropic forms of enargite, "rose enargite," the high temperature form, orthorhombic, and "green enargite," the low temperature form, isometric.

One of the most important contributions of the whole book is the description of the etching behavior of the minerals. The effect of each of the common reagents is clearly and fully stated. This is a great advance over the tabular method of presentation. The author has done his etching by immersing the whole section in a small dish of the reagent and for this reason we find no reference to those reactions, such as effervescence and the attack by fumes, which are best observed under the microscope. Acidified $KMnO_4$ is used with great effect. It develops structure in the following sulphides: Sphalerite, wurzite, nicolite, pyrite, marcasite, cobaltite (only effective etching reagent), chalcopyrite, and enargite (from some localities). Where twinning is present in these minerals it is brought out. It attacks chloanthite and smaltite without developing structure. Alkaline $KMnO_4$ develops structure in the following: Arsenopyrite, chalcopyrite, bournonite (only reagent except alkaline H_2O_2), enargite (from some localities), and stannite. With both these reagents a precipitate can generally be removed by HCl. Electrolytic etching with HCl is used to develop structure in pyrrhotite. This test distinguishes pyrrhotite from pentlandite and is useful in contrasting the minerals. Galena also shows good grain structure when etched electrolytically with dilute HCl.

Under the heading "Inner character of the individuals" a large store of valuable information is to be found. No other systematic description gives this information, those in common use being hampered in this respect by their tabular form. The following subjects are discussed: "Speed of Solution in Different Crystallographic Directions;" this information is important both in explaining etch structure in an aggregate and in judging the effect of a reagent when only a few random grains are available for testing; for example, stibnite is little affected by KOH parallel to 010 but is strongly attacked parallel to 001; "Etch Cleavage," the orientation and appearance are given; "Twinning Lamellæ;" Schneiderhöhn brought these out in a large number of minerals. Their presence is valuable in showing the structure of a one-mineral aggregate. They may have unexpected significance, for example: The crystal forms of cobaltite indicate hemihedral (pyritohedral) symmetry. Schneider-

höhn states that recently Mechling [4] has shown by X-ray examination that crystals of cobaltite from Tunaberg show a tetartohedral isometric symmetry by this method of investigation. Schneiderhöhn studied a single specimen and shows that it is strongly anisotropic and that it shows a well defined polysynthetic twinning. He concludes that the isometric crystals have undergone an inversion at a temperature below that at which they were formed. From his observations and by analogy with polymorphic pyrite and marcasite he suggests the likelihood of cobaltite altering to an orthorhombic form, and suggests the verification of this by lauegraphically investigating material selected after careful chalcographic examination.[5] "Zonal structure" is described where present. "Deformation," particularly where its effect is shown on twinning lamellæ, is recorded. "Characteristic inclusions," earlier discussed in this review, are noted. Finally, there are given for each mineral the criteria which distinguish it from all other minerals investigated. One must so often decide between minerals having similar properties that it is most useful to have a clear statement as to how any mineral may be distinguished from those minerals which closely resemble it.

The make-up of the book is excellent, the arrangement is good, barring minor features, for example, several important etching reagents are mentioned in the special part under the first mineral where used instead of in the general section on etching. The printing is good and the illustrations of polished sections well chosen, from well prepared specimens, and excellently reproduced. The use of plates is lavish. Where one plate represents several features it is reproduced several times.

In conclusion, Schneiderhöhn undertook a large task, and with the material at hand has done much. He has used new methods very effectively. Indeed, in the use of polarized light he has started where others left off, realizing the possibilities of the method of investigation, and applying it with success. Schneiderhöhn says that "genetic relations . . . had to be set aside and will find their place in a volume entitled, 'Gefügebilder von Erzlagerstätten,' which he hopes will appear soon." We join him in his wish.

EDWARD SAMPSON.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

[4] In Rinne, *Knst. Feinbaustudien Abh. Sächs. Akad. Wiss.*, vol. 38, No. 3, 1921.

[5] The reviewer in verifying Schneidehöhn's observations found that well crystallized material from the following localities was composed of rather strongly anisotropic grains: Tunaberg, Sweden (2 lots), Enngrufoona, Sweden, Quartzburg district, Grant Co., Ore., Cobalt, Ont. None showed such perfect polysynthetic twinning as figured by Schneiderhöhn, but most did show more or less multiple banded twinning in addition to granular structure. It may be noted that before

Die Entstehung eisenreicher Gesteine durch Halmyrolyse (=submarine Gesteinszersetzung). K. HUMMEL, Geologische Rundschau, vol. 13, 1922, pp. 42–81 and 97–136.

This paper is a valuable addition to the study of sediments. The author points out that "halmyrolysis" (*decomposition* of rocks on the sea bottom, as opposed to *diagenesis*) can be compared with lateritic weathering on land, and that it is chiefly responsible for the formation of glauconite and similar granular and oölitic iron-rich sediments. The material making up the granules is the residue of decomposed minerals, chiefly silicates, and as it is in the form of a gel, it tends to form granules. Their formation in extensive beds takes place only in areas where sedimentation is not faster than decomposition.

In the first part of the paper the formation and positions of recent glauconite deposits are discussed at length (accompanied by an extensive bibliography) because glauconite is practically the only mineral of this group which can be studied in the process of formation today. It is shown that extensive beds of glauconite seem to form only in regions where cold and warm ocean currents meet and where the resultant temperature is between 3° and 15° C. As such water contains much more oxygen than warmer water, its oxidizing effect on rock and organic matter at the bottom of the sea will be much stronger. Accordingly, decomposition of organic matter and accompanying halmyrolysis are rapid. How this organic matter acts is unknown. (For a suggestion the reviewer may be permitted to refer to his own paper in ECON. GEOL., vol. 17, 1923, p. 433.) Bacteria may have had a part in the decomposition. Most of the bases, however, and a large part of the silica and alumina are leached from the original sediments. The residue is an iron-rich colloidal substance. The potash of the glauconite may be an original constituent of the rock, or more probably, may have been adsorbed from the sea water.

As oxygen is not lacking during most of the halmyrolysis, the end product is a ferric compound—glauconite. It is, of course, not difficult to imagine that the silica carried away is deposited elsewhere as chert or some other siliceous sediment in a region adjoining the glauconite sands. A number of pages are devoted to the interpretation of paleoclimatic and paleogeographic conditions under which glauconite sediments were formed.

The second part of the paper, dealing with the formation of oölitic iron ores and similar deposits, is not as convincing as the first. As we have no recent oölitic iron ores, their formation necessarily must be more

these crystals were etched with acid $KMnO_4$ they appeared perfectly isotropic. Perhaps this was due to surface heating during polishing.

speculative. However, it appears that oölitic textures and ores have formed in relatively warm water. It has often been observed that glauconites and oölites in appreciable quantities do not occur together in the same bed, though they may occur in alternating layers. The fact that oölitic iron-bearing sediments often contain more ferrous iron, either as carbonate or silicate, than ferric iron, is explained as being due chiefly to the smaller amount of oxygen in relatively warm (above 15° C.) sea water in which the oölites form.

On the other hand, the frequent occurrence of oölites consisting at least partly of primary ferric oxide or hydroxide cannot be accounted for in this manner. The author comes to the conclusion that these were probably formed in suspension in the oxygen-rich surface waters, or that they were carried upward by strong currents into these oxygen-rich layers and there remained long enough for the oxidation of a part of the ferrous iron. (It seems to the reviewer that such an explanation is not quite in agreement with the rest of the author's views.) The most probable original source of the iron oölites is found in the basic igneous rocks, especially tuffs, often associated with the oölites. The iron-rich sediments usually formed after a period of great volcanic activity. However, Hummel is opposed to the idea that magmatic exhalations could have furnished iron directly to the sediments, chiefly because a benthonic fauna is very common in them. Repetition of some of the subject matter in the paper accounts partly for its length of 78 pages.

JOHN W. GRUNER.

SOCIETY OF ECONOMIC GEOLOGISTS

The following candidates have been nominated for officers for 1924 by the Nominating Committee, consisting of E. DeGolyer, Chairman, W. C. Mendenhall, and Willet G. Miller.

For President

Ralph Arnold
James F. Kemp
C. K. Leith

For Vice-President

Edson S. Bastin
Ezequiel Ordonez
Joseph T. Singewald

For Councilor

Ernest Andrews
George H. Ashley
Millard K. Shaler

For Councilor

Cassius A. Fisher
James H. Gardner
D. F. Hewett

SCIENTIFIC NOTES AND NEWS

W. C. Mendenhall, L. M. Prindle, A. C. Lawson, and Arthur Keith have been in Vermont for a field conference.

W. S. Bayley has completed his work on the iron ores of eastern Pennsylvania and adjacent portions of New Jersey.

Charles Camsell and Charles Stewart, Canadian Minister of the Interior, will attend the Economic Conference in London to confer on matters relating to the mineral industry.

H. D. Miser, of the U. S. Geological Survey, is in Tulsa, Oklahoma, to begin field and office consultation in connection with the preparation of a geologic map of Oklahoma.

George C. Branner has been appointed State Geologist of Arkansas.

Alfred Wandke, of Harvard University, has left for central Mexico, where he will be with the Guanajuato Consolidated Mining and Milling Company, City of Guanajuato.

Charles P. Berkey and R. J. Colony have been studying the geological problems of the Schunnemunk Mountain region for the New York State Geological Survey.

E. F. Burchard, of the U. S. Geological Survey, has been making a geological investigation of the bauxite deposits near Louisville, Miss.

D. B. Dowling, of the Canadian Geological Survey, has been investigating artesian well possibilities in a dry area near Peace River, the reported discoveries of placer gold and platinum in the Red Deer district, and the petroleum areas of southern Alberta.

Malcolm Maclaren has been spending some time in the vicinity of the Premier Mine in northern British Columbia.

A. J. Bancroft, of McGill University, and E. J. Conway, field engineer for the Granby Company, have been in the Salmon River district of British Columbia, examining the Sunshine and George Copper groups of claims.

C. H. Behre, Jr., of Lehigh University, has been mapping and studying in detail the slate deposits in northeastern Pennsylvania for the Pennsylvania Topographic and Geologic Survey, under the direction of R. W. Stone.

R. E. Somers, of the University of Pittsburgh, has spent the summer in the field as geologist for the Greensboro Gas Company and the Chartiers Oil Company.

R. W. Stone is directing field work in connection with testing the molding sands of Pennsylvania, samples of which are being collected from widely scattered deposits throughout the state. The tests will be made in the laboratory of Professor H. Ries at Cornell University.

Charles McCrea has been appointed Minister of Mines for the province of Ontario, Canada.

Alfred Whitman, of the University of California, is making an examination of the Castle Trethewey mine of Gowganda.

Walter Harvey Weed has been at Wallace, Idaho, engaged in professional work for the Callahan Zinc-Lead Company.

E. L. Bruce, of the Ontario Department of Mines, has been investigating the recent report of the discovery of gold at Red Lake, in the District of Patricia.

G. H. Ashley, State Geologist of Pennsylvania, spent part of August in the French River country, Ontario, Canada, and the Sudbury district.

It is with deep regret that we record the death of Horace V. Winchell in Los Angeles.

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